

(NASA-TM-109193) DEBRIS/ICE/TPS
ASSESSMENT AND INTEGRATED
PHOTOGRAPHIC ANALYSIS FOR SHUTTLE
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Debris/Ice/TPS Assessment and Integrated Photographic Analysis for Shuttle Mission STS-60

March 1994



National Aeronautics and
Space Administration

ORIGINAL CONTAINS
COLOR ILLUSTRATIONS

Debris/Ice/TPS Assessment and Integrated Photographic Analysis for Shuttle Mission STS-60

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Space Administration





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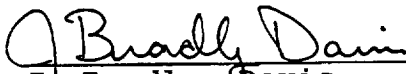
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OF
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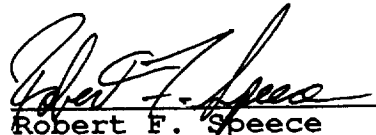
February 3, 1994

Prepared By:

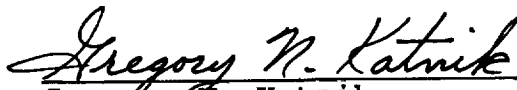

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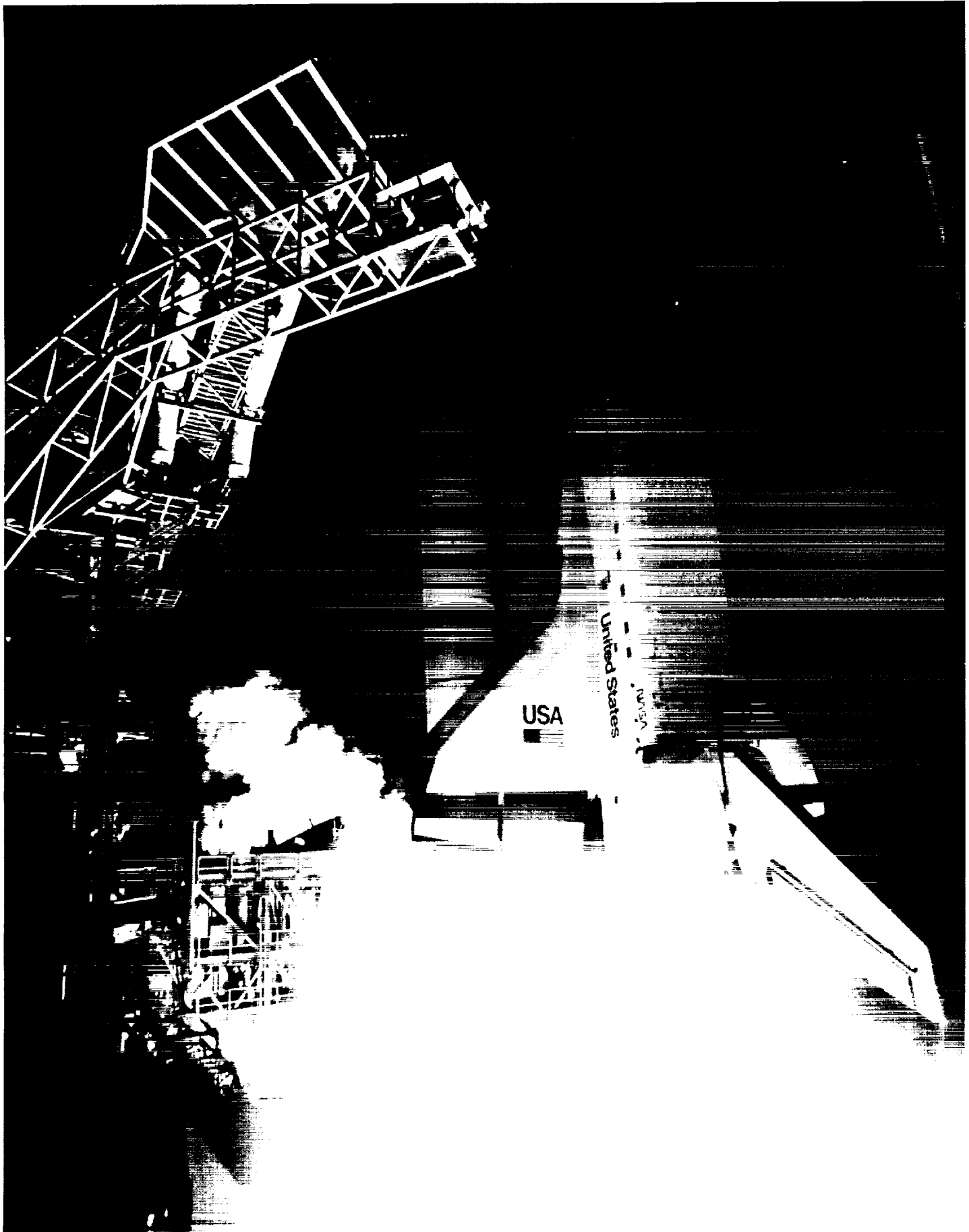
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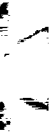
FOREWORD

The Debris Team has developed and implemented measures to control damage from debris in the Shuttle operational environment and to make the control measures a part of routine launch flows. These measures include engineering surveillance during vehicle processing and closeout operations, facility and flight hardware inspections before and after launch, and photographic analysis of mission events.

Photographic analyses of mission imagery from launch, on-orbit, and landing provide significant data in verifying proper operation of systems and evaluating anomalies. In addition to the Kennedy Space Center (KSC) Photo/Video Analysis, reports from Johnson Space Center, Marshall Space Flight Center, and Rockwell International - Downey are also included in this document to provide an integrated assessment of the mission.



Shuttle Mission STS-60 was launched at 7:10 a.m. local 2/3/94



1.0 Summary

A pre-launch debris inspection of the pad and Shuttle vehicle was conducted on 2 February 1994. The detailed walkdown of Launch Pad 39A and MLP-3 also included the primary flight elements OV-103 Discovery (18th flight), ET-61 (LWT 54), and BI-062 SRB's. There were no significant facility or vehicle anomalies.

The vehicle was cryoloaded on 2 February 1994. There were no Launch Commit Criteria (LCC), OMRs, or NSTS-08303 criteria violations. There were no ice/frost conditions outside of the established data base and no IPR's were taken.

Although acreage icing on the External Tank was possible due to an ambient temperature of 44 degrees, winds averaging 9 knots and lower than expected relative humidity of 79 percent caused only frost to form on a mostly condensate-free tank. Patches of frost were visible on the LO2 tank barrel section and the upper part of the LH2 tank.

After the 7:10 a.m. launch on February 3rd, a debris inspection of Pad 39A was performed. No flight hardware or TPS materials were found. Damage to the pad overall was minimal. The GH2 vent line was latched on the fifth tooth of the latching mechanism and had no loose cables (static retract lanyard).

A total of 120 films and videos were analyzed as part of the post launch data review. No major vehicle damage or lost flight hardware was observed that would have affected the mission. No stud hang-ups occurred on any of the holddown posts. All T-0 umbilicals operated properly.

On-orbit photographs taken by the flight crew of the External Tank after separation from the Orbiter revealed no major damage or lost flight hardware that would have been a safety of flight concern. The intertank-to-LH2 tank flange closeout was intact and no divots were visible. The bipod jack pad closeouts appeared to be intact also. There were no divots in the intertank acreage foam. TPS eroded/ablated on the LH2 tank aft dome apex and manhole covers, which is a normal occurrence.

The Solid Rocket Boosters were inspected at Hanger AF after retrieval. Both frustums had a combined total of 21 MSA-2 debonds over fasteners. The cover on the LH frustum upper right BSM was bent backward to the 90 degree position and the attach ring had been deformed/fractured by parachute riser entanglement. The HDP #3 DCS plunger was obstructed by a frangible nut half. Although launch films showed no debris falling from the DCS/stud hole at lift off, post flight disassembly of the Debris Containment System revealed a retention of only 53 percent. The ordnance fragments may have been lost at water impact. The HDP #4 DCS plunger was obstructed by a frangible nut web and small ordnance fragments.

A post landing inspection of OV-103 was conducted after the landing at KSC. The Orbiter TPS sustained a total of 106 hits, of which 15 had a major dimension of 1-inch or larger. The Orbiter lower surface had a total of 48 hits, of which 4 had a major dimension of 1-inch or larger. Based on these numbers and comparison to statistics from previous missions of similar configuration, both the total number of debris hits and the number of hits 1-inch or larger was less than average.

A greater than usual number of tile damage sites occurred on the leading edges of the OMS pods and vertical stabilizer. Eleven of these hits had a major dimension larger than 1-inch. Depths ranged from 1/8 to 3/4 inches. This type of damage is usually attributed to impacts from higher density material, such as ice from the waste water dump. The shim in the EO-2 "salad bowl" was partially debonded and displaced across the stud hole approximately 1/4-inch. No debris was found on the runway beneath the ET/ORB umbilical cavities.

Orbiter post landing microchemical sample results revealed a variety of residuals in the Orbiter window samples that were attributed to SRB BSM exhaust, Orbiter TPS, natural landing site products, and paints/primers from various sources. These residual sampling data do not indicate a single source of damaging debris as all of these materials have been documented previously in post-landing sample reports. The residual sample data also showed no debris trends when compared to previous mission data.

A total of seven Post Launch Anomalies, but no IFA's, were observed during the STS-60 mission assessment.

2.0 PRE-LAUNCH BRIEFING

The Ice/Debris/TPS/Photographic Analysis Team briefing for launch activities was conducted on 2 February 1994 at 0800 hours. These personnel participated in various team activities, assisted in the collection/evaluation of data, and contributed to reports contained in this document.

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J. Blue	LSOC - SPC	ET Processing
Z. Byrns	NASA - KSC	Level II Integration
C. Martin	NASA - KSC	Level II Integration
J. Stone	RI - DNY	Debris Assess, LVL II Integ
K. Thompson	RI - LSS	Vehicle Integration
J. Cook	MTI - LSS	SRM Processing
S. Otto	MMMSS- LSS	ET Processing
J. Burney	LSOC - SPC	Safety

3.0 LAUNCH

STS-60 was launched at 94:034:12:10.000 GMT (7:10 a.m. local) on 3 February 1994.

3.1 PRE-LAUNCH SSV/PAD DEBRIS INSPECTION

A pre-launch debris inspection of the pad and Shuttle vehicle was conducted on 2 February 1994. The detailed walkdown of Launch Pad 39A and MLP-3 also included the primary flight elements OV-103 Discovery (18th flight), ET-61 (LWT 54), and BI-062 SRB's. There were no significant facility or vehicle anomalies.

3.2 ICE/FROST INSPECTION

The Ice/Frost Inspection of the cryoloaded vehicle was performed on 2 February 1994 from 0245 to 0415 hours during the two hour built-in-hold at T-3 hours in the countdown. There were no Launch Commit Criteria, OMRS, or NSTS-08303 criteria violations. There were no conditions outside of the established data base and no IPR's were taken. Ambient weather conditions at the time of the inspection were:

Temperature:	44.4 Degrees F
Relative Humidity:	79.2 Percent
Wind Speed:	8.9 Knots
Wind Direction:	306 Degrees

A portable Shuttle Thermal Imager (STI) infrared scanning radiometer was utilized to obtain vehicle surface temperature measurements for an overall thermal assessment of the vehicle, as shown in Figures 1 and 2.

3.3 ORBITER

No Orbiter tile or RCC panel anomalies were observed. All RCS thruster paper covers were intact. Due to the prevailing weather conditions, somewhat greater than usual ice and frost accumulations were present at the SSME #1 and #2 heat shield-to-nozzle interfaces. An infrared scan revealed no unusual temperature gradients on the base heat shield or engine mounted heat shields.

3.4 SOLID ROCKET BOOSTERS

SRB case temperatures measured by the PSTI/Cyclops spot radiometer ranged from 40 to 47 degrees F. The SRB GEI measured temperatures ranging from 45 to 48 degrees F. This was the second flight using reduced GEI instrumentation with only four case acreage temperature sensors per SRM. All measured temperatures were above the 34 degrees F minimum requirement.

FIGURE 1. **SSV INFRARED SCANNER SURFACE TEMPERATURE SUMMARY DATA**

TIME: 0250-0415
 DATE: 2-3-94
 VEH. STS- 60
 Temperatures in °F

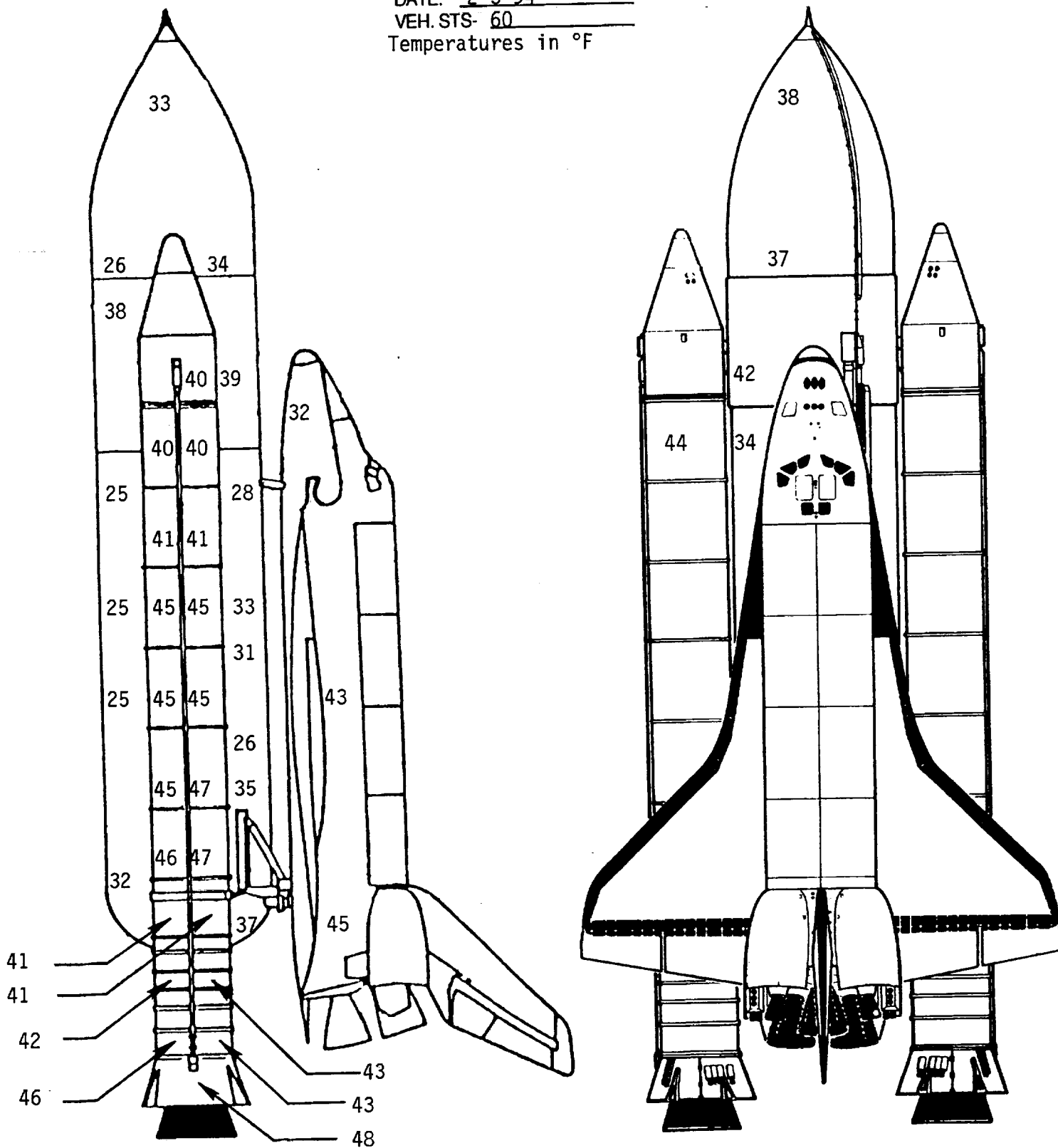
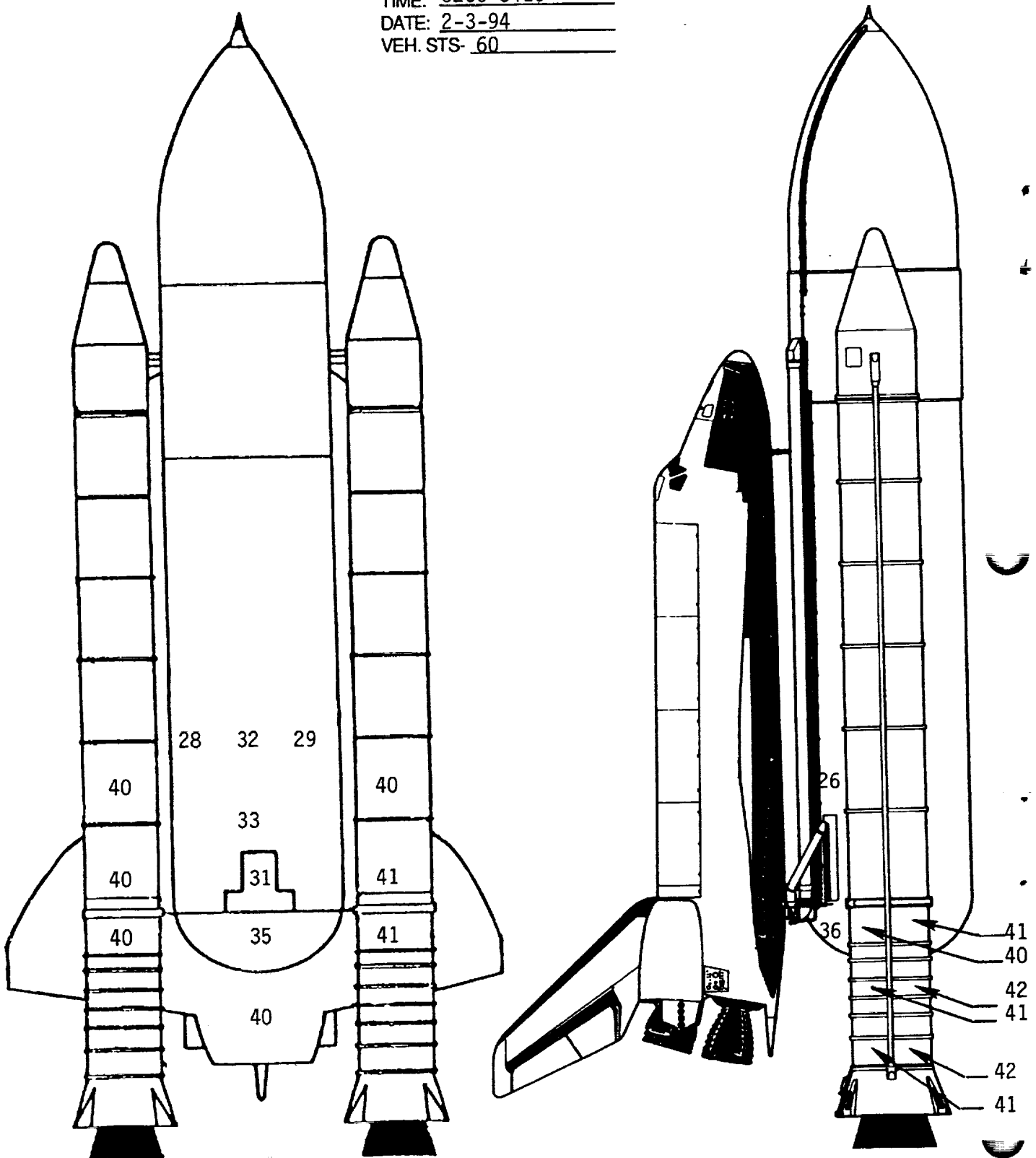


FIGURE 2. **SSV INFRARED SCANNER
SURFACE TEMPERATURE
SUMMARY DATA**

TIME: 0250-0415
DATE: 2-3-94
VEH. STS- 60



The predicted Propellant Mean Bulk Temperature (PMBT) supplied by MTI was 61 degrees F, which was within the required range of 44-86 degrees Fahrenheit.

3.5 EXTERNAL TANK

The ice/frost prediction computer program 'SURFICE' was run from 2300 to 0700 hours and the results tabulated in Figure 3. The program predicted ice/frost formation or freezing runoff condensate (Region III) on the TPS acreage surfaces after cryoload.

The Ice Team observed no ice accumulations on the LO2 tank ogive. Light frost had formed on the barrel section. There were no acreage TPS anomalies. Surface temperatures as measured by the infrared radiometer averaged 35 degrees F on the ogive and 26 degrees F on the barrel section. In comparison, SURFICE predicted temperatures of 28 degrees F on the ogive and 25 degrees F on the barrel.

The intertank acreage exhibited no TPS anomalies. Typical ice/frost accumulation, but no unusual vapor, was present on the ET umbilical carrier plate. The radiometer measured a surface temperature of 40 degrees F.

There were no LH2 tank acreage TPS anomalies. Light frost, but no ice, was present on the acreage. Heavier accumulations of ice/frost had formed along the edges of the PAL ramps, cable tray ramps, pressurization line ramps, and longerons. The portable STI/Cyclops measured surface temperatures averaging 27 degrees F on the upper LH2 tank and 34 degrees F on the lower LH2 tank. In comparison, SURFICE predicted temperatures of 26 degrees F on the upper LH2 tank and 32 degrees F on the lower LH2 tank.

The bipod jack pad closeouts were intact and flush with adjacent foam.

A 10-inch long by 1/2-inch wide crack in the -Y vertical strut cable tray forward surface TPS near the longeron closeout interface was acceptable for flight per the NSTS-08303 criteria and required no IPR.

Typical amounts of ice/frost were present in the LO2 feedline bellows and support brackets.

There were no TPS anomalies on the LO2 ET/ORB umbilical. Ice/frost fingers on the separation bolt pyrotechnic canister purge vents were typical.

Ice/frost in the LH2 recirculation line bellows and on both burst disks was typical. The LH2 feedline bellows and the in-board side of the feedline straight section were frost covered.

STS- 60	TEST	S0007 LAUNCH										DATE: 3 February 1994										T-0 TIME: 07:10.000 ES										NASA				
ORBITER 103	ET	SRB	MLP	PAD	LO2	CHILLDOWN TIME: 00:26					FAST FILL TIME: 00:22					CHILLDOWN TIME: 23:34					FAST FILL TIME: 23:34					KSC										
	61	BI-082	3	A		SLOW FILL TIME: 02:28					REPLENISH TIME: 02:08					SLOW FILL TIME: 23:45					REPLENISH TIME: 02:08					Ice/Frost/Debris										
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Typical amounts of ice/frost had accumulated on the LH2 ET/ORB umbilical purge barrier. Typical ice/frost fingers had formed on the pyro canister and plate gap purge vents. Ice/frost was present on the aft pyrotechnic canister closeout bondline indicating a thermal short. Ice/frost had formed from the 17-inch flapper valve actuator access port foam plug forward corner to the aft pyro canister closeout. No unusual vapors or cryogenic drips had appeared during tanking, stable replenish, and launch.

The summary of Ice/Frost Team observations/anomalies, which were all acceptable for launch per the NSTS-08303 criteria, consisted of four OTV recorded items:

Anomaly 001 (documentation only) recorded ice/frost formations on the LO2 feedline support brackets and bellows.

Anomaly 002 (documentation only) recorded ice/frost formations on the LO2 and LH2 ET/ORB umbilicals, pyro can purge vents, purge barrier, and LH2 recirculation line bellows/burst discs.

Anomaly 003 documented a crack 10-inches long by 1/2-inch wide in the -Y vertical strut cable tray forward surface TPS. The crack exhibited no offset and was not filled with ice or frost.

Anomaly 004 documented frost accumulations on various areas of the LO2 and LH2 tank acreage.

3.6 FACILITY

All SRB sound suppression water troughs were filled and properly configured for launch (LCC requirement).

No leaks were observed on either the LO2 or LH2 Orbiter T-0 umbilicals, the GH2 vent line, or the GUCP.

No ET nosecone/footprint damage was visible after the GOX vent hood was retracted. No icicles had formed on the GOX vent ducts

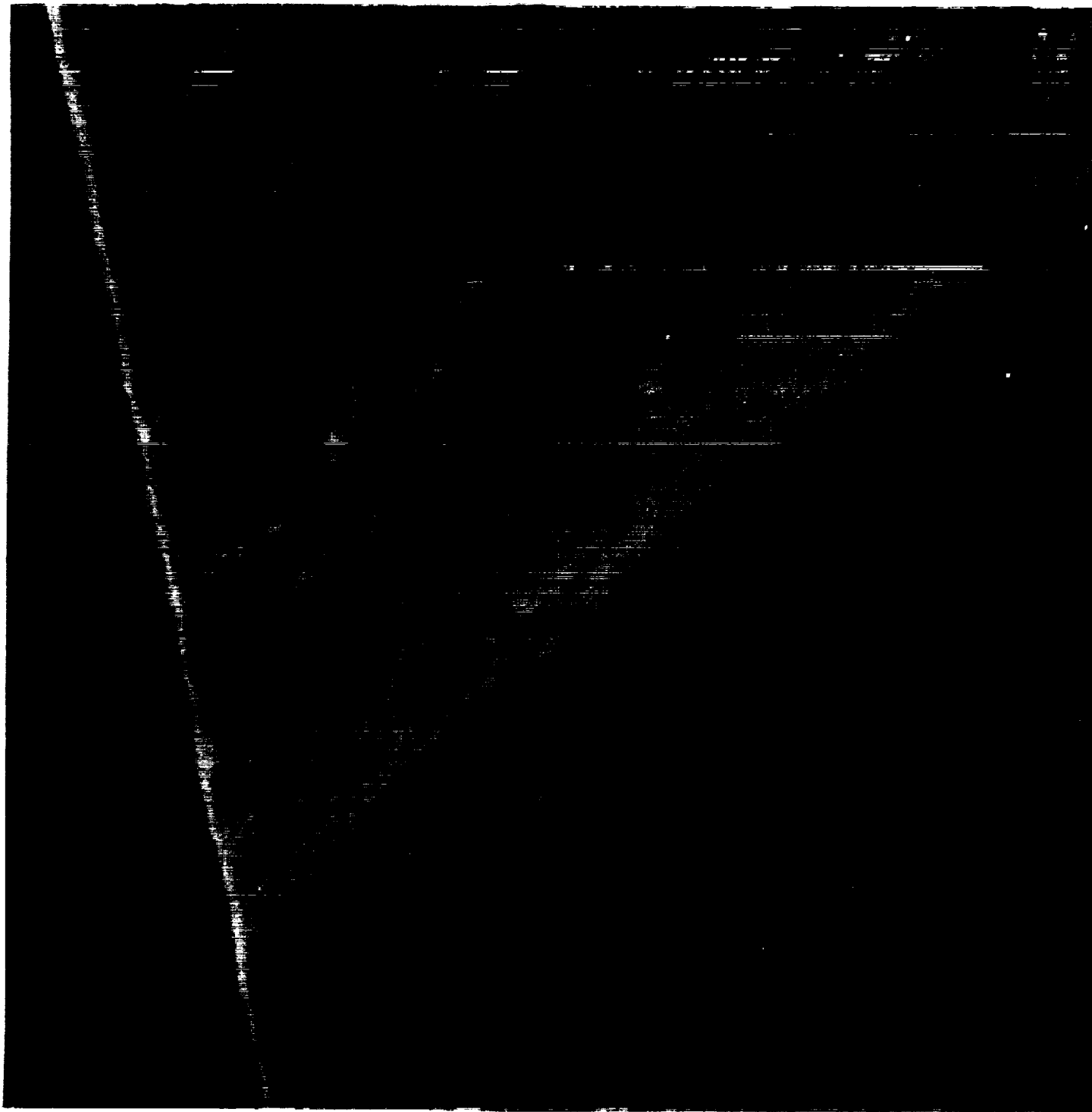
Launch Accessories reported a hydraulic leak in the Orbiter Access Arm retract system. However, the Ice Team found no indications of a leak at the OAA console on the FSS 175 foot level or at the OAA hinge on the FSS 195 foot level.





Pre-launch configuration of bipod jack pad closeouts





Light frost, but no ice or significant amounts of condensate, were present on the External Tank acreage after cryogenic loading. The frost melted shortly after sunrise. There were no ice/frost LCC violations prior to launch.





Some ice/frost had formed on most of the protuberance to L02 and LH2 tank acreage interfaces. The presence of this ice/frost was acceptable for flight per the NSTS-08303 criteria.



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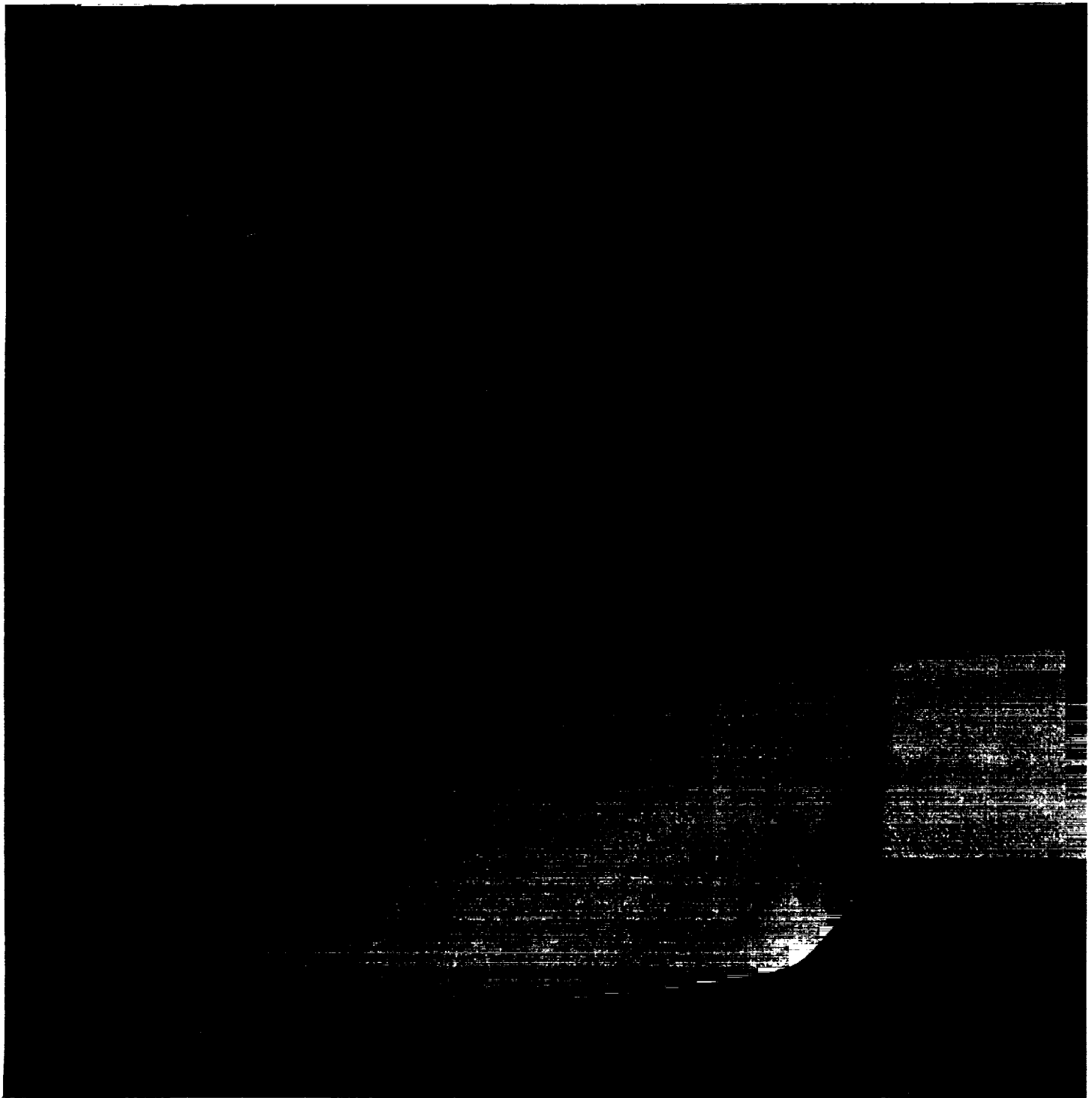
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A crack, 10 inches long by 1/2 inch wide, appeared in the forward surface of the -Y ET/SRb cable tray after cryoload. The crack was not filled with ice or frost and exhibited no offset.



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Less than usual amounts of ice/frost had accumulated on the ET/ORB LH2 umbilical. Ice/frost on the plate gap and pyro can purge vents was typical. Some frost had formed along the LH2 feedline support bracket to acreage interface. No cryogenic drips or unusual vapors appeared during tanking and stable replenish.



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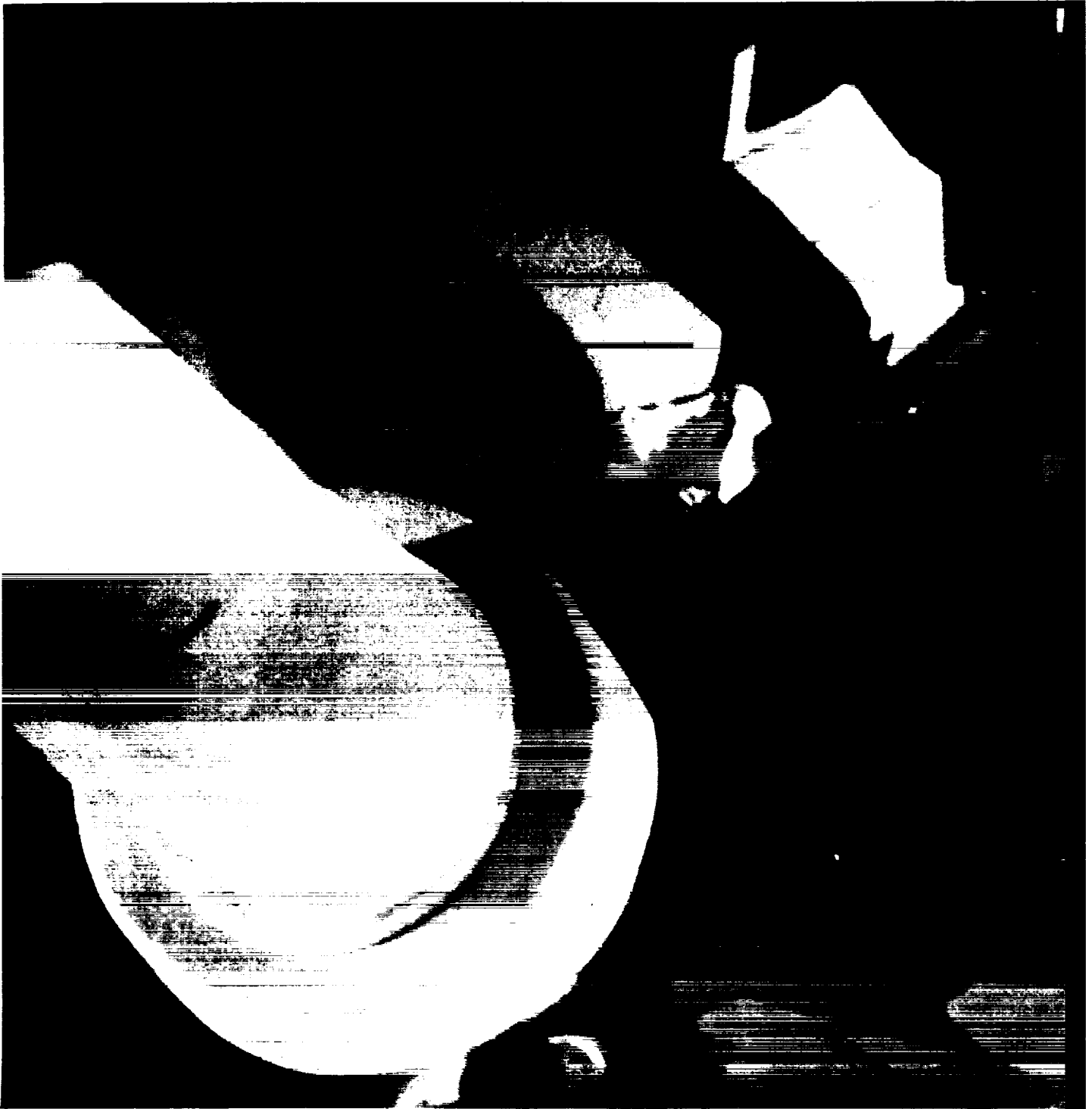
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Ice/frost accumulation on the plate gap and pyro can purge vents, LH2 recirculation line bellows and burst discs was typical. Ice/frost had formed along the LH2 feedline to acreage interface from the TPS plug to the pyro can closeout. No cryogenic drips or unusual vapors appeared during tanking and stable replenish.



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4.0 POST LAUNCH PAD DEBRIS INSPECTION

The post launch inspection of the Mobile Launch Platform, Fixed Service Structure and Rotating Service Structure was conducted on 3 February 1994 from Launch + 3 to 4.5 hours.

No flight hardware or TPS materials were found.

South SRB HDP erosion was typical. All south HDP shoe EPON shim material was intact, but significantly debonded on HDP #1 and #2. There was no visual indication of a stud hang-up on any of the south holddown posts. All of the north HDP doghouse blast covers were in the closed position. The SRB aft skirt purge lines and T-0 umbilicals exhibited typical exhaust plume damage.

A bolt was loose on the E-7 camera pedestal near HDP #4.

A 36 inch long piece of metal hand rail screen material from the ET intertank access structure was found on the southwest corner of the MLP deck wrapped around a permanent hand rail. Impact marks were visible on the deck. A similar piece of material 24 inches in length was found on the southwest pad apron.

The Tail Service Masts (TSM), Orbiter Access Arm (OAA), and GOX vent arm showed only minor damage.

The GH2 vent line was latched on the fifth tooth of the latching mechanism, had no loose cables (static retract lanyard) and appeared to have latched properly with no rebound.

Typical damage to the facility included several loose/detached panel doors cable tray covers on the FSS and RSS. This type of damage usually occurs after the vehicle clears the tower and is not considered a debris threat.

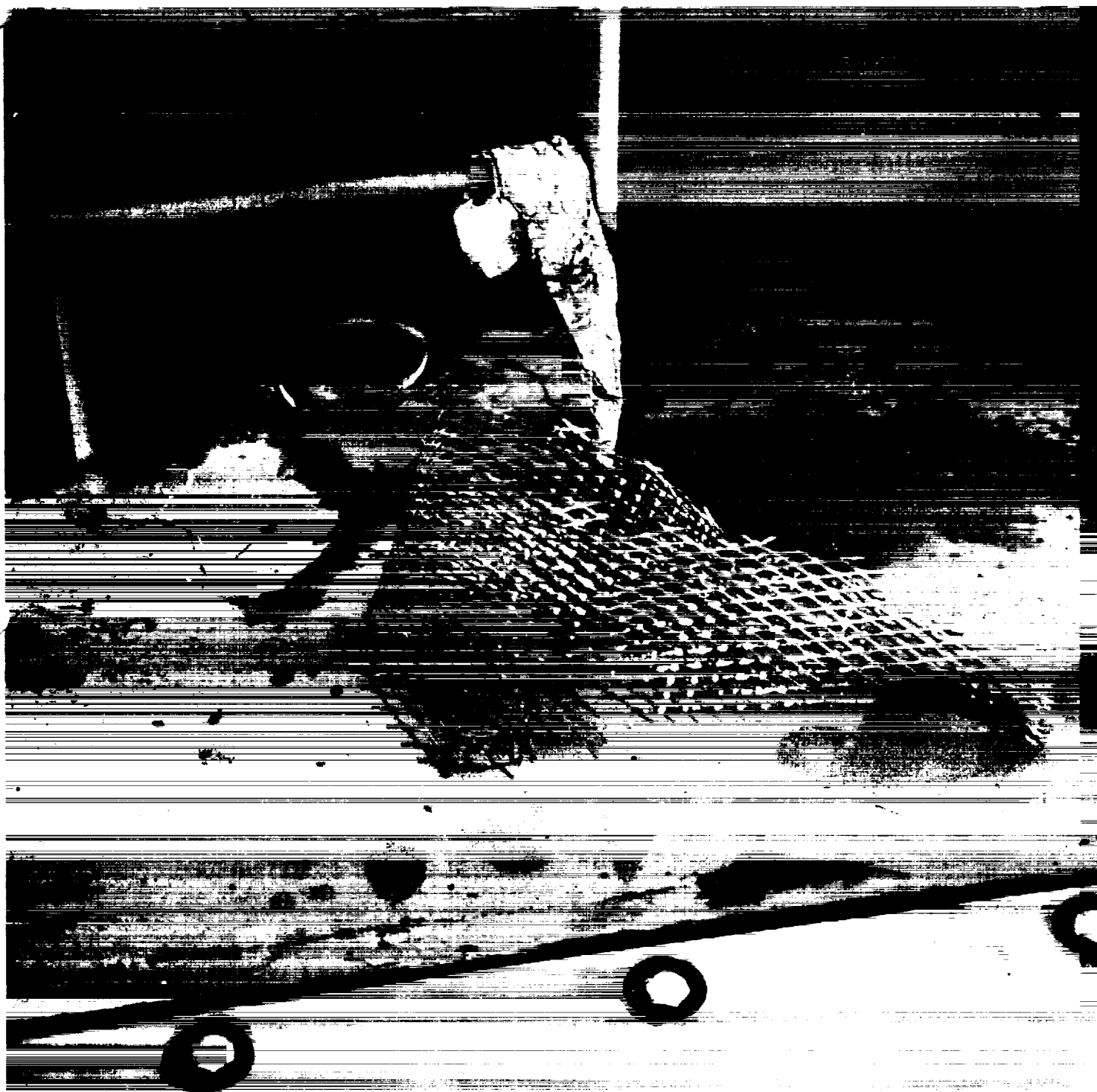
All seven emergency egress slidewire baskets were secured on the FSS 195 foot level and sustained no launch damage.

Debris inspections of the pad acreage, north flame trench, beach, and areas outside the pad perimeter were performed. No flight hardware or TPS material was found. Post launch pad inspection anomalies are listed in Section 9.



South SRB HDP erosion was typical. All south HDP shoe EPON shim material was intact, but significantly debonded on HDP #1 and #2.





A 36 inch long piece of metal hand rail screen material from the ET intertank access structure was found on the southwest corner of the MLP deck wrapped around one of the permanent hand rail. The screen material came off after the vehicle cleared the tower.



1

2



3

4



5.0 FILM REVIEW AND PROBLEM REPORTS

Anomalies observed in the Film Review were presented to the Mission Management Team, Shuttle managers, and vehicle systems engineers. No In-Flight Anomalies were generated as a result of the film review. Post flight anomalies are listed in Section 9.

5.1 LAUNCH FILM AND VIDEO SUMMARY

A total of 105 films and videos, which included forty-one 16mm films, twenty-one 35mm films, three 70mm films, and forty videos, were reviewed starting on launch day.

No major vehicle damage or lost flight hardware was observed that would have affected the mission.

During SSME ignition, free burning hydrogen was blown south by prevailing winds and drifted upward to the LH OMS pod. SSME ignition and gimbal profile appeared normal (OTV 051, 063, 070, 071). Mach diamonds formed in the SSME #2 and #1 exhaust plumes almost simultaneously, which may indicate SSME #2 was somewhat slow in starting (E-76). A flash occurred in the SSME plume during ignition (E-2).

Fore-and-aft movement of the Orbiter base heat shield in the centerline area between the SSME cluster occurred during engine start-up. The motion was similar to that observed on previous launches (E-77).

Surface coating material was lost from base heat shield tiles outboard of SSME #3 (2 places), near the RH OMS nozzle heat shield (13 places), and from the aft surface of the ACPs stinger (1 place) (E-17, 19). Tile surface coating material, approximately 1" x 1" in size, appeared near the body flap hinge area/outer edge and fell aft at 12:09:57.096 GMT (E-18).

SSME ignition caused numerous pieces of ice to fall from the ET/Orbiter umbilicals. Some pieces of ice contacted the umbilical cavity sill and were deflected outward, but no tile damage was visible (OTV 009).

A piece of mylar tape from the ET/ORB umbilical purge barrier (baggie) fell from the inboard corner of the LH2 umbilical past the RH inboard elevon during SSME ignition (OTV 009, E-6, 17).

A piece of plastic or tape first appeared near the RH SRB and moved in the direction of the L02 ET/ORB umbilical (OTV 054).

A light colored particle, most likely a piece of ice, was first visible near the -Y ET/SRB aft strut fairing and fell downward without contacting the vehicle (E-31).

No stud hang-ups occurred on any of the holddown posts. No ordnance fragments or frangible nut pieces fell from any of the DCS/stud holes. One piece of RH SRB aft skirt thermal curtain tape was loose (E-7).

A greater than usual amount of ejecta (throat plug material, instafoam particles, deck/paint scale) from the RH SRB exhaust hole crossed the field of view after T-0 (E-7). A thin, rigid, dark object, most likely deck or paint scale, was ejected upward out of the RH SRB exhaust hole, moved south, and passed the east side of the L02 TSM (E-5).

SRB sound suppression water trough cloth parts tags crossed the field of view after T-0 (E-5, 9).

The Orbiter LH2 and L02 T-0 umbilicals disconnected and retracted properly (OTV 049, 050, 063, E-17, E-18). GUCP disconnect from the External Tank was nominal (E-33). The GH2 vent line appeared to latch normally (OTV 060, E-41, 42, 50). There was no excessive slack in the static retract lanyard. Post launch inspection found the GH2 vent line latched on the fifth tooth of the latching mechanism.

Numerous debris objects were visible in the SSME plume exiting the south flame trench after the vehicle cleared the tower (E-62, 63, 76).

A light colored object, most likely an FRCS thruster paper cover, first appeared near the base of the vertical stabilizer and fell aft past SSME #1 (E-213, frame 3466).

Pieces of RCS paper covers were visible passing over the Orbiter wings (E-59, 213, 222).

Five flashes occurred in the SSME plume during ascent (E-205, 207, 211, 213, 223, 224).

Body flap movement (amplitude and frequency) was similar to previous flights (E-213).

Numerous SRB propellant particles fell out of the plume during ascent (E-213, 220, TV-4A).

ET aft dome charring and exhaust plume recirculation were typical (TV-13). Numerous pieces of slag fell out of the SRB plumes before, during, and after separation (TV-4A, TV-21A). SRB plume tailoff and separation appeared normal (E-208, 212, 220).

The SRB frustums appeared to separate from the forward skirts properly. Parachute deployment and reefing appeared normal. Although dark due to the time of day, splashdown was visible (E-301, 302).



Surface coating material was lost from base heat shield tiles outboard of SSME #3 (2 places), near the RH OMS nozzle heat shield (13 places), and from the aft surface of the ACPS stinger (1 place).



5.2 ON-ORBIT FILM AND VIDEO SUMMARY

Thirty-seven hand held still images and fifteen minutes of video were obtained by the flight crew of the External Tank after separation from the Orbiter. All surfaces of the External Tank were photographed with the exception of the +Y+Z quadrant. OV-103 was not equipped to carry ET/ORB umbilical cameras.

No major damage or lost flight hardware was observed that would have been a safety of flight concern.

The intertank-to-LH2 tank flange closeout was intact and no divots were visible. The bipod jack pad closeouts appeared to be intact. There were no divots in the intertank acreage TPS.

The BSM burn scars on the LO2 tank were typical. No anomalies occurred on the nosecone, LO2 tank acreage, PAL ramps, RSS antennae, flight door, bipod ramps, LH2 tank acreage, LO2 feed line, and aft hardpoint.

TPS eroded/ablated on the LH2 tank aft dome apex and manhole covers, which is a normal occurrence. The aft dome acreage NCFI was charred, but showed no erosion or divots.

5.3 LANDING FILM AND VIDEO SUMMARY

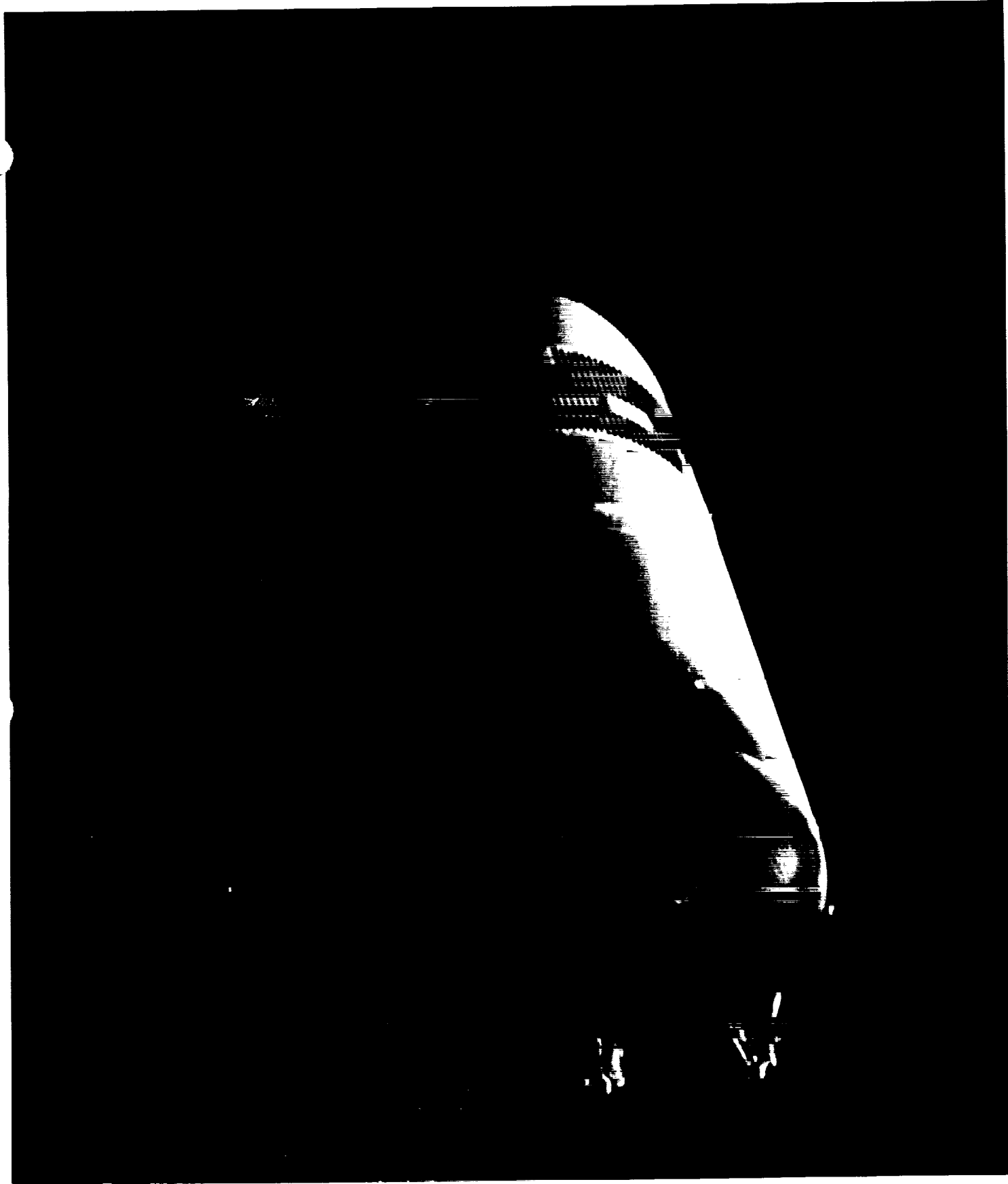
A total of fourteen videos, six 16mm films, and nine 35mm large format films were reviewed.

Orbiter performance on final approach appeared normal. There were no anomalies when the landing gear was extended. Touchdown of the left and right main gear was nominal and almost simultaneous.

The drag chute was deployed after breakover, but before the nose gear contacted the runway. Drag chute deployment appeared nominal. The chute was blown slightly westward (+Y side of the Orbiter) by prevailing winds.

Touchdown of the nose landing gear was smooth.

Black tiles on the LH OMS pod leading edge exhibited some damage.



TPS eroded/ablated from the External Tank LH2 aft dome apex and manhole covers - a normal occurrence. The aft dome acreage NCFI was charred, but showed no erosion or divots. Five light colored spots on the LH2 tank acreage near the -Z axis were areas sanded smooth during ground processing.





The intertank-to-LH2 tank flange was intact and no divots were visible. The bipod jack pad closeouts appeared to be intact also. There were no divots in the intertank acreage TPS.



6.0 SRB POST FLIGHT/RETRIEVAL DEBRIS ASSESSMENT

Both Solid Rocket Boosters were inspected for debris damage and debris sources at CCAFS Hangar AF on 7 February 1994 from 0830 to 1030 hours. From a debris standpoint, both SRB's were in good condition.

6.1 RH SOLID ROCKET BOOSTER DEBRIS INSPECTION

The RH frustum was missing no TPS but had 10 MSA-2 debonds over fasteners. There was virtually no blistering of the Hypalon paint with the exception of minor localized blistering along the 395 kick ring. All BSM aero heat shield covers were locked in the fully opened position (Figure 4).

The RH forward skirt acreage exhibited no debonds or missing TPS. Both RSS antennae covers/phenolic base plates were intact. Minor blistering of the Hypalon paint occurred on the systems tunnel cover and around the ET/SRB attach point. No pins were missing from the frustum severance ring.

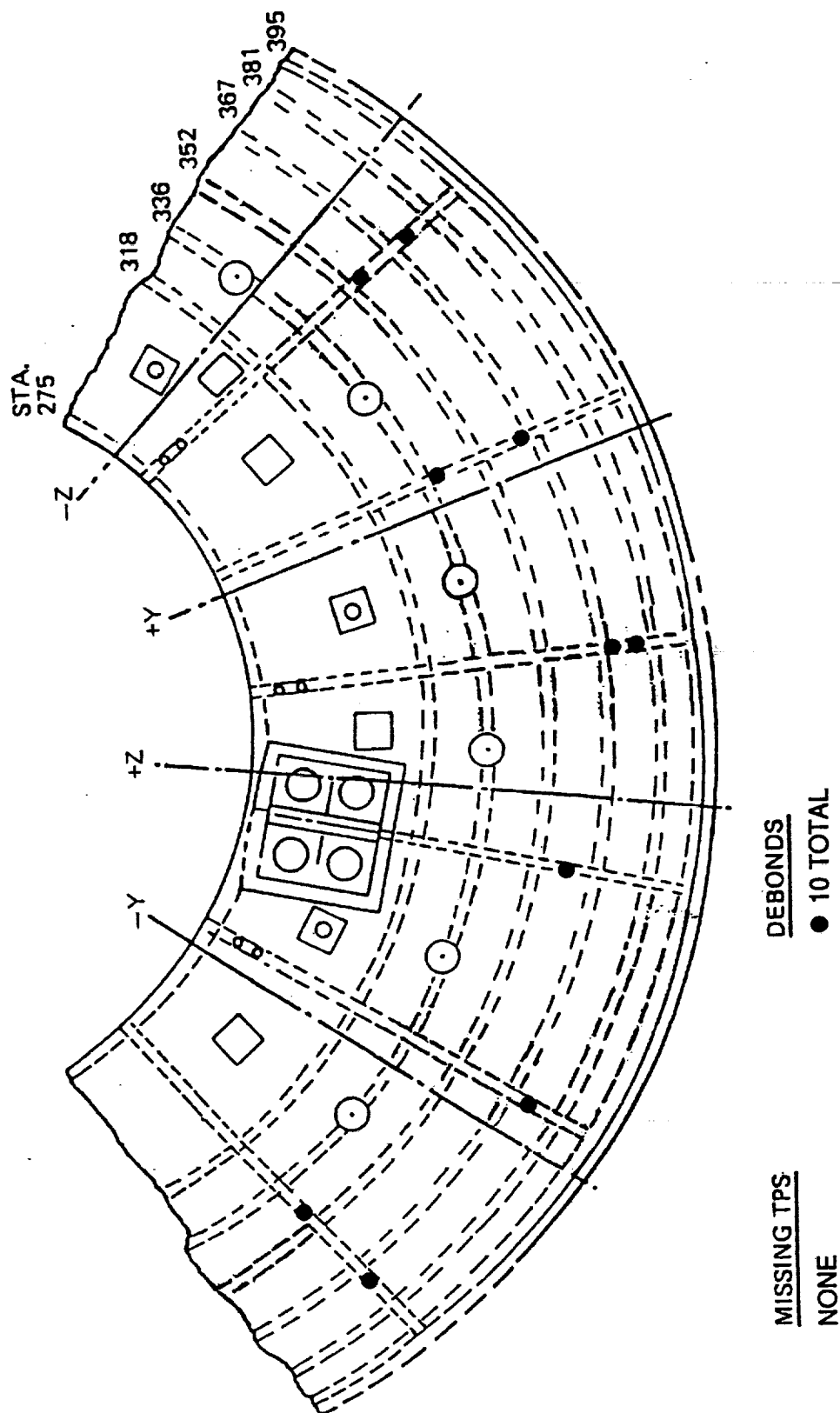
The Field Joint Protection System (FJPS) closeouts were generally in good condition. Trailing edge damage to the FJPS and the GEI cork runs were attributed to debris resulting from severance of the nozzle extension. Some foam (PDL) spillage adhered to the aft field joint closeout near the 270 degree axis and may have originated from the forward ET/SRB attach point closeout.

Separation of the aft ET/SRB struts appeared normal. The ET/SRB aft struts, ETA ring, IEA, IEA covers, and stiffener rings appeared undamaged. The aft booster stiffener ring splice plate closeouts were intact and no K5NA material was missing.

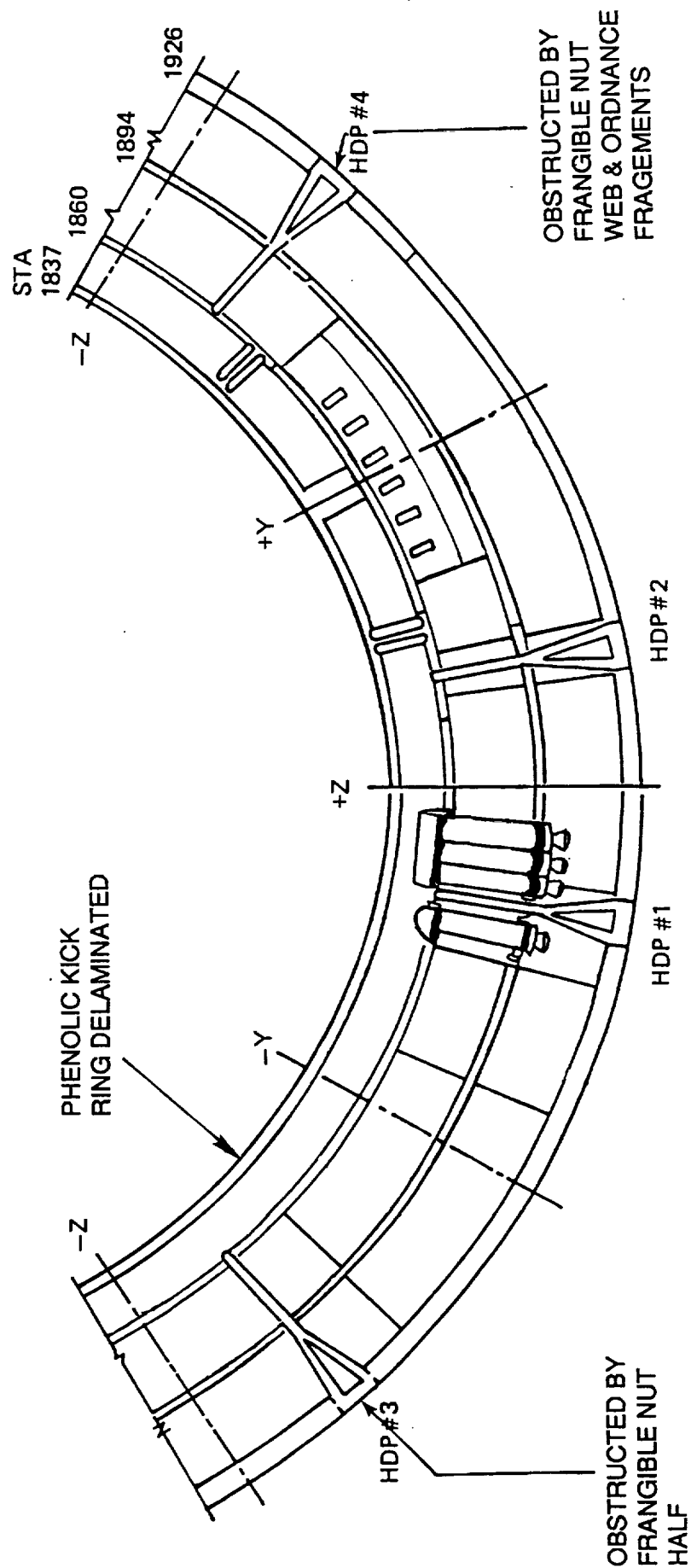
The phenolic material on the kick ring was delaminated. Aft skirt acreage TPS was generally in good condition. Hypalon paint was blistered/missing from the BTA closeouts (Figure 5).

HDP #1 and #2 Debris Containment System (DCS) plungers were seated and appeared to have functioned properly. The HDP #3 DCS plunger was obstructed by a frangible nut half. Although launch films showed no debris falling from the DCS/stud hole at lift off, post flight disassembly of the Debris Containment System revealed a retention of only 53 percent. The ordnance fragments may have been lost at water impact. The HDP #4 DCS plunger was obstructed by a frangible nut web and small ordnance fragments. EPON shim material is no longer bonded to the HDP #3 and #4 aft skirt structure.

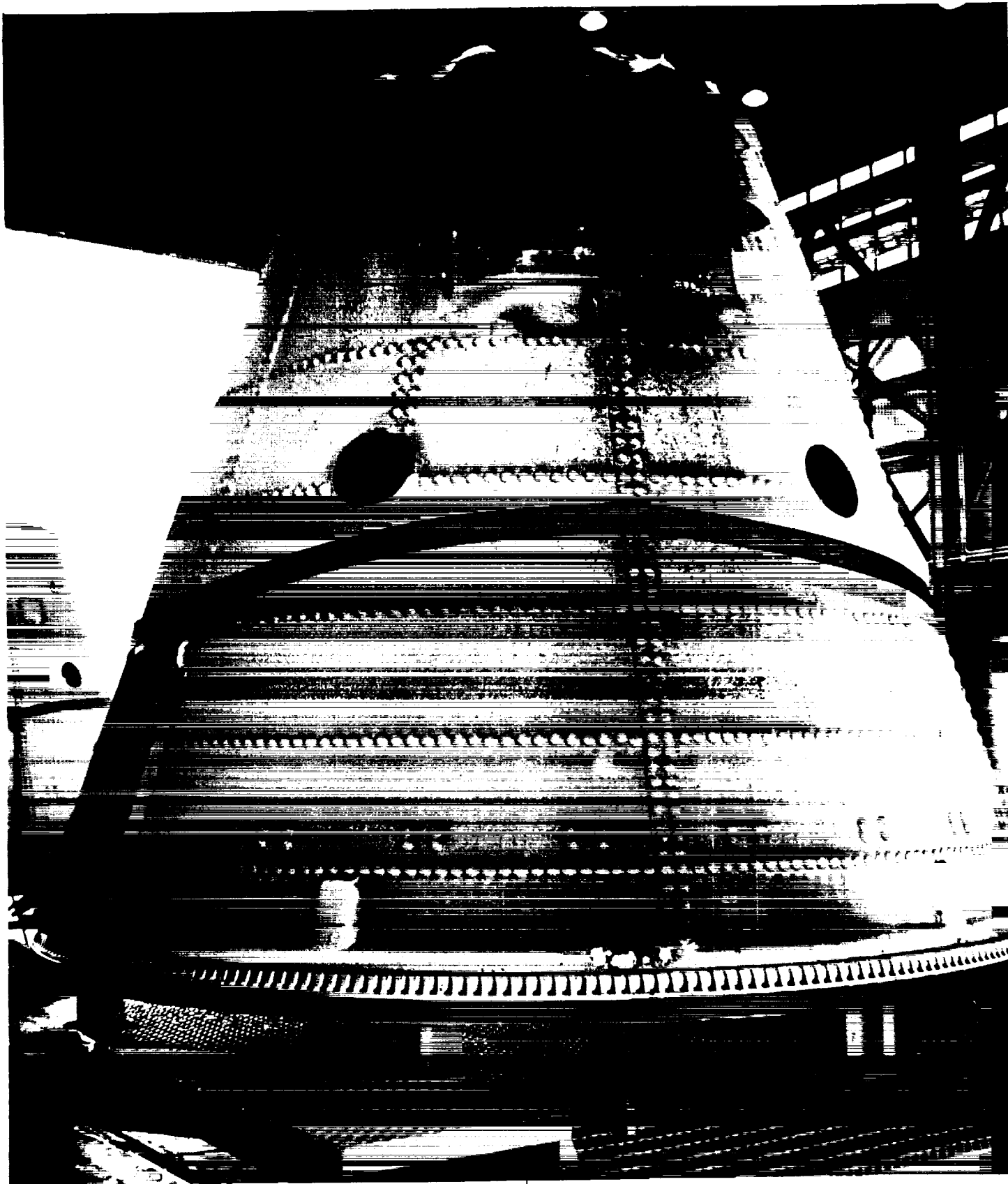
STS-60
FIGURE 4. RIGHT SRB FRUSTUM



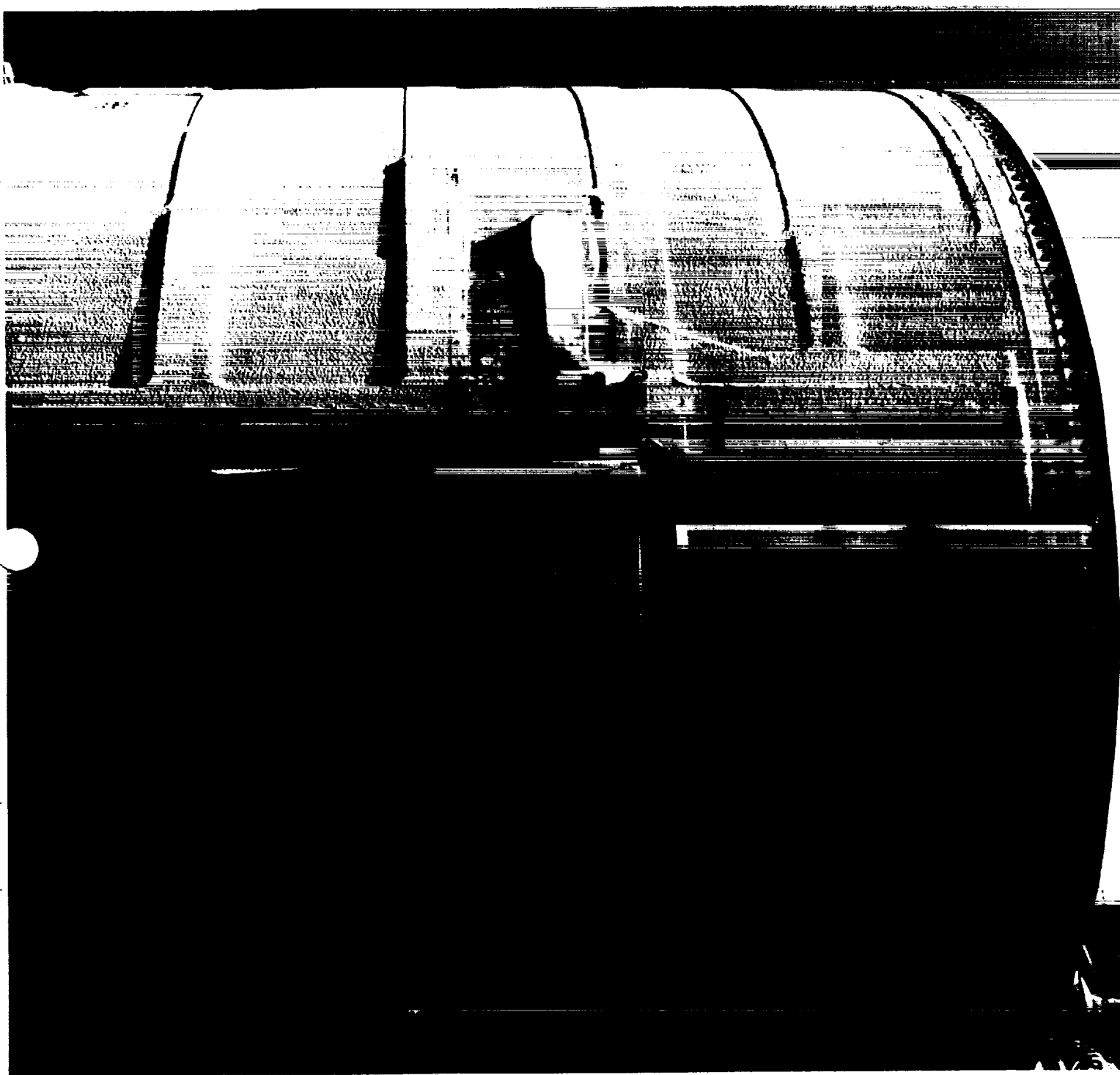
STS-60
 FIGURE 5. RIGHT SRB AFT SKIRT EXTERIOR TPS







The RH frustum was missing no TPS, but had 10 MSA-2 debonds over fasteners. The BSM aero heat shield covers were locked in the fully opened position. There was virtually no blistering of the Hypalon paint.



RH forward skirt acreage exhibited no debonds or missing TPS. Minor blistering of the Hypalon paint occurred near the ET/SRB attach point.



Some foam (PDL) spillage adhered to the aft field joint closeout near the 270 degree axis and may have originated from the forward ET/SRB attach point closeout.



1

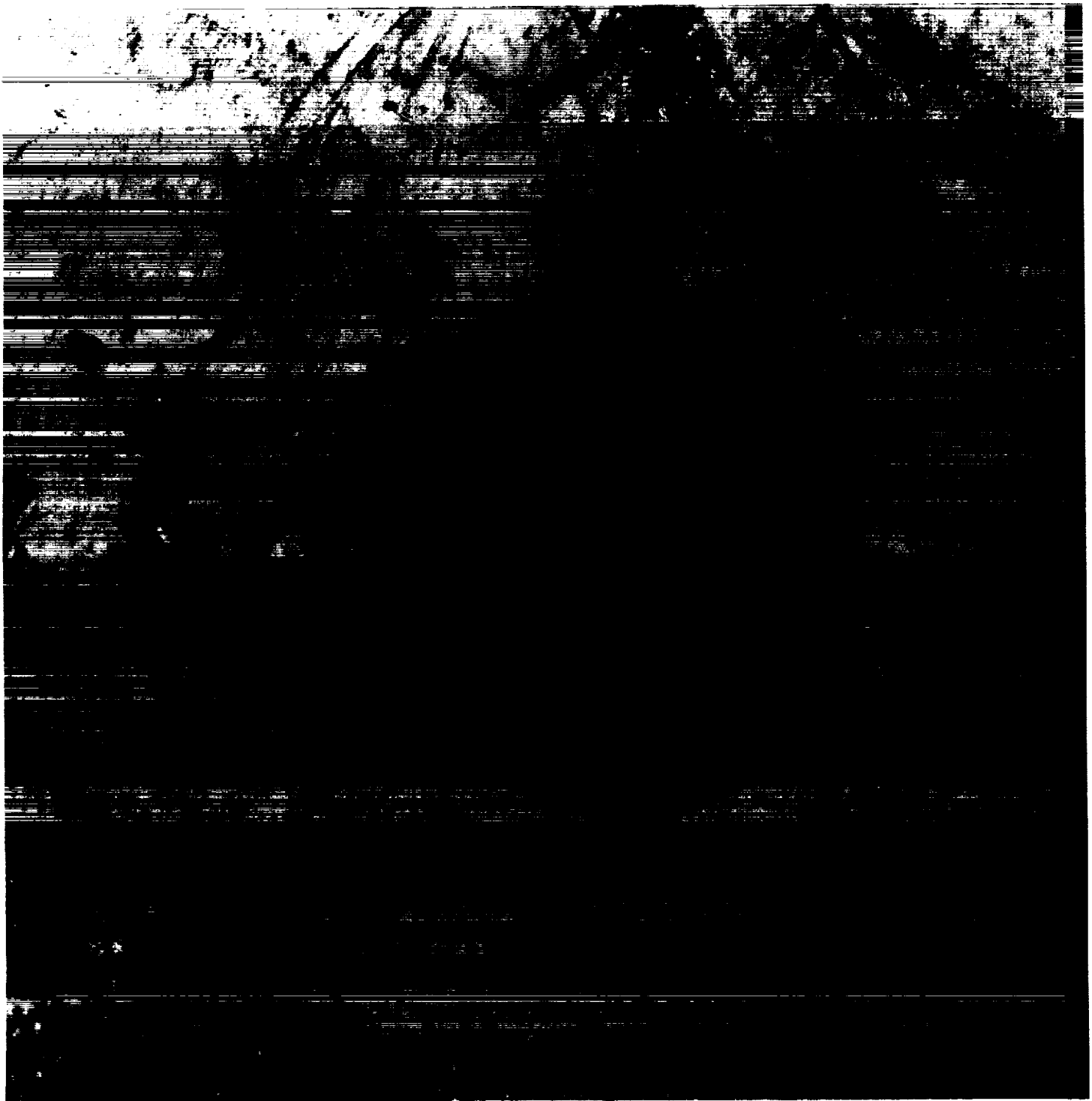
2



3

4





The HDP #3 DCS plunger was obstructed by a frangible nut half. Launch films showed no debris falling from the stud hole at liftoff. Post flight disassembly of the DCS revealed a retention of 53 percent.



6.2 LH SOLID ROCKET BOOSTER DEBRIS INSPECTION

The LH frustum was missing no TPS but had 11 MSA-2 debonds over fasteners. There was virtually no blistering of the Hypalon paint with the exception of minor localized blistering along the 395 ring (Figure 6). All BSM aero heat shield covers had locked in the fully opened position. However, the upper right cover was bent backward to the 90 degree position and the attach ring had been deformed/fractured by parachute riser entanglement.

The LH forward skirt acreage exhibited no debonds or missing TPS. Both RSS antennae covers/phenolic base plates were intact. Minor blistering of the Hypalon paint occurred near the ET/SRB attach point and on the systems tunnel cover. No pins were missing from the frustum severance ring.

The Field Joint Protection System (FJPS) closeouts were in good condition. In general, minor trailing edge damage to the FJPS and the GEI cork runs were attributed to debris resulting from severance of the nozzle extension.

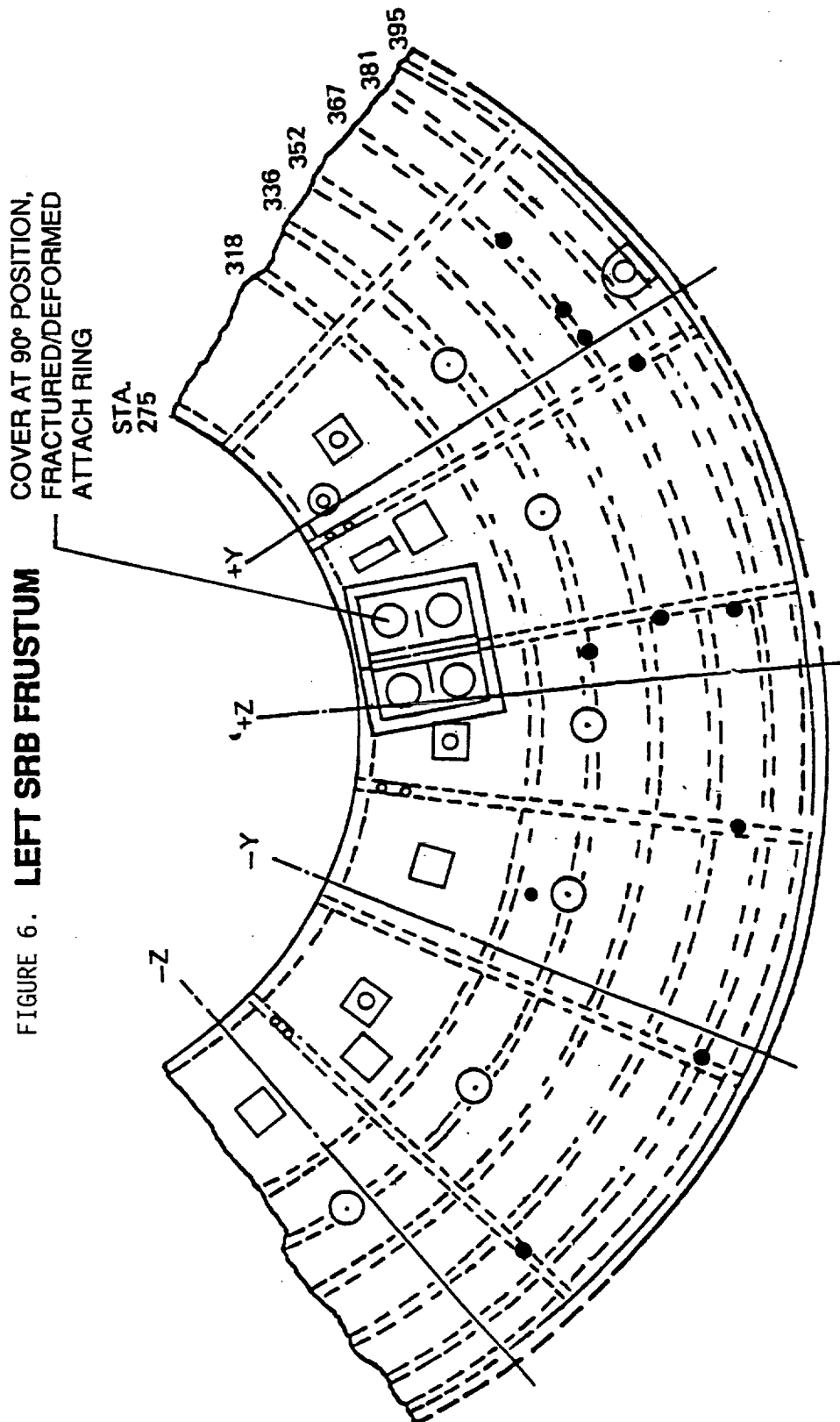
Separation of the aft ET/SRB struts appeared normal. The ET/SRB aft struts, ETA ring, IEA, IEA covers, and stiffener rings appeared undamaged. The stiffener ring splice plate closeouts were intact and no K5NA material was missing.

The phenolic material on the kick ring was delaminated. Aft skirt acreage TPS was generally in good condition, though MSA-2 was missing from four places on the 1860 ring frame and near the HDP #7 foot (Figure 7). The largest area of missing TPS measured 4" x 2". No significant amount of BTA was used on the aft skirt closeouts. A greater than usual amount of instafoam, typically applied at the launch pad, was missing from the aft skirt aft ring. Exposed sections of K5NA were sooted and showed signs of heating.

All four Debris Containment System (DCS) plungers were seated and appeared to have functioned properly. EPON shim material is no longer bonded to the HDP #7 and #8 aft skirt structure.

SRB Post Launch Anomalies are listed in Section 9.

STS-60
FIGURE 6. LEFT SRB FRUSTUM

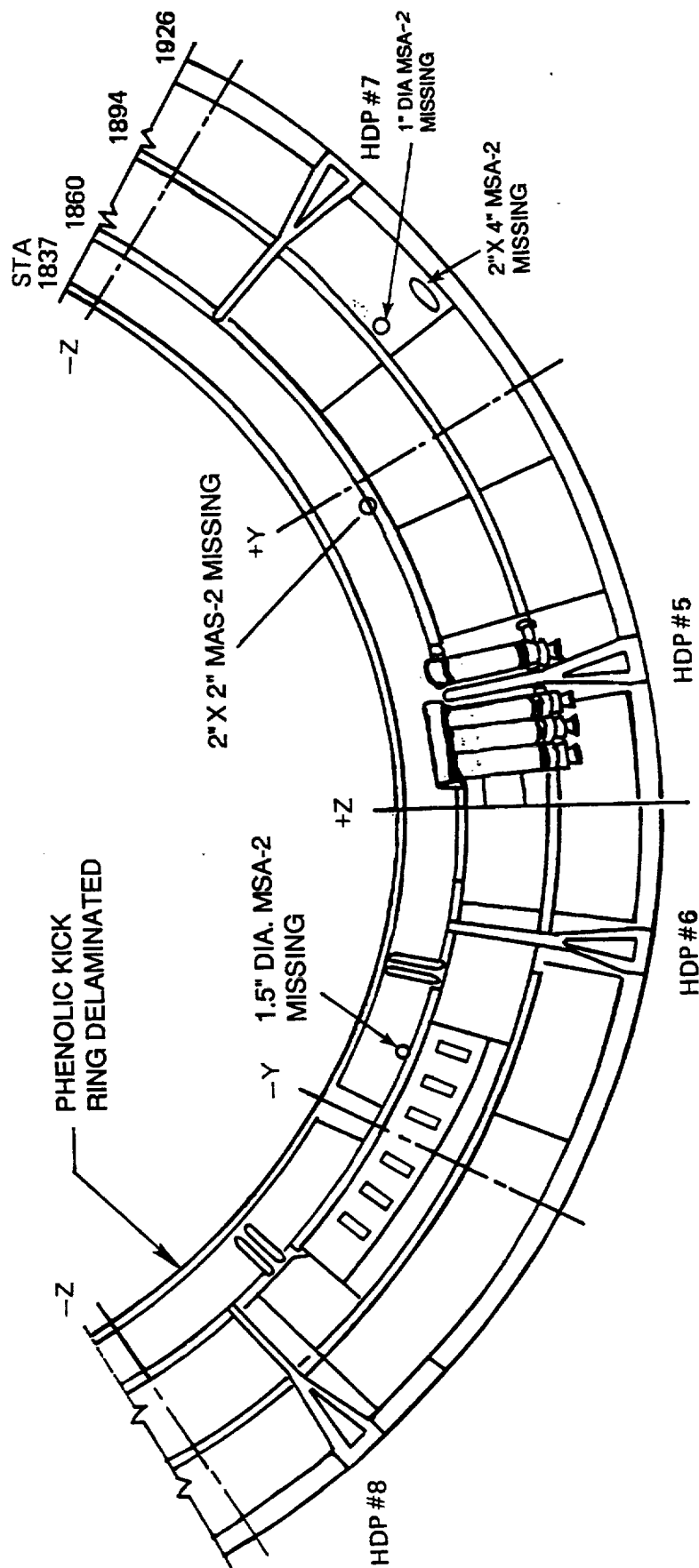


MISSING TPS
NONE

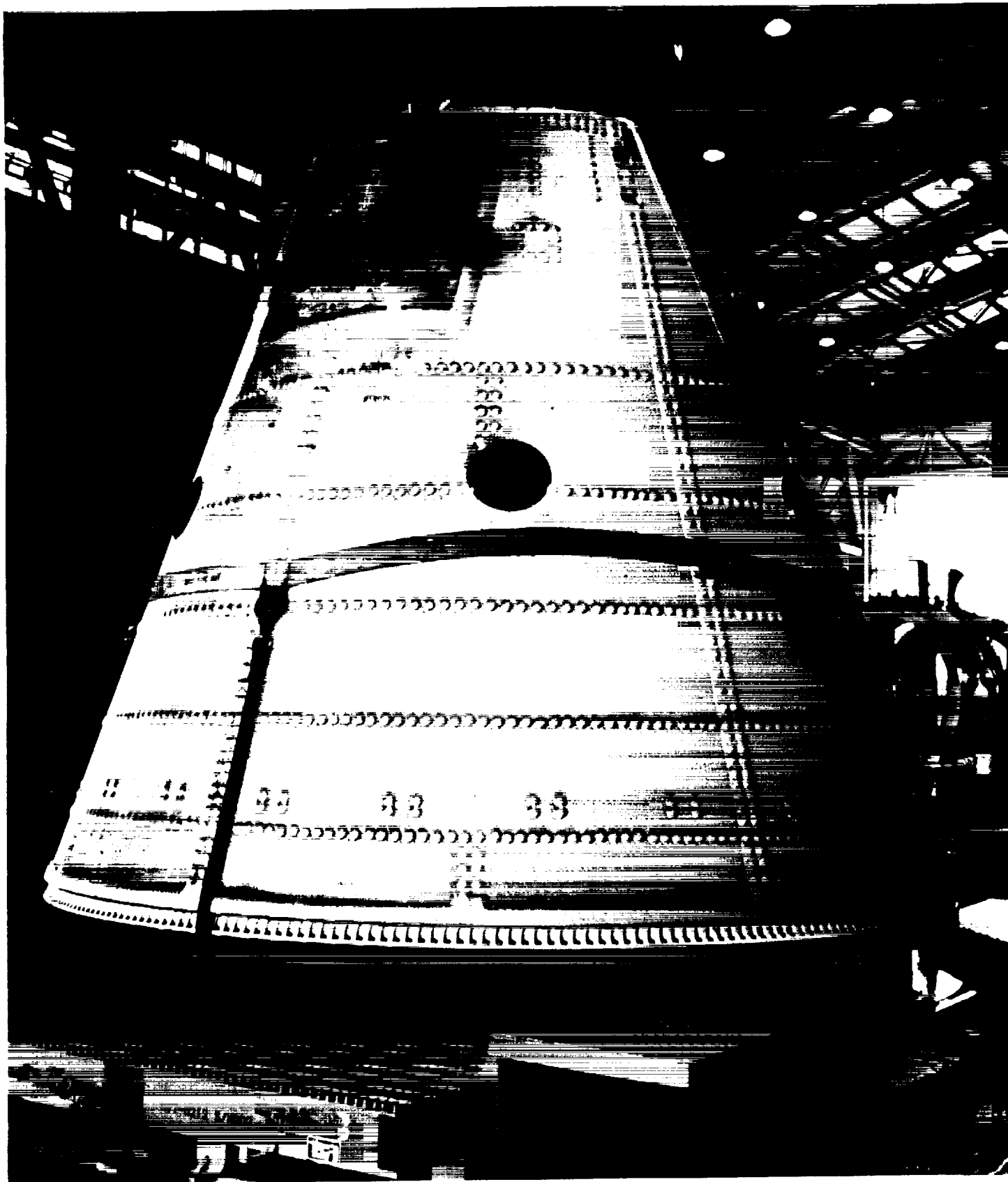
DEBONDS
● 11 TOTAL

STS-60

FIGURE 7. LEFT SRB AFT SKIRT EXTERIOR TPS



ALL DCS PLUNGERS
SEATED PROPERLY

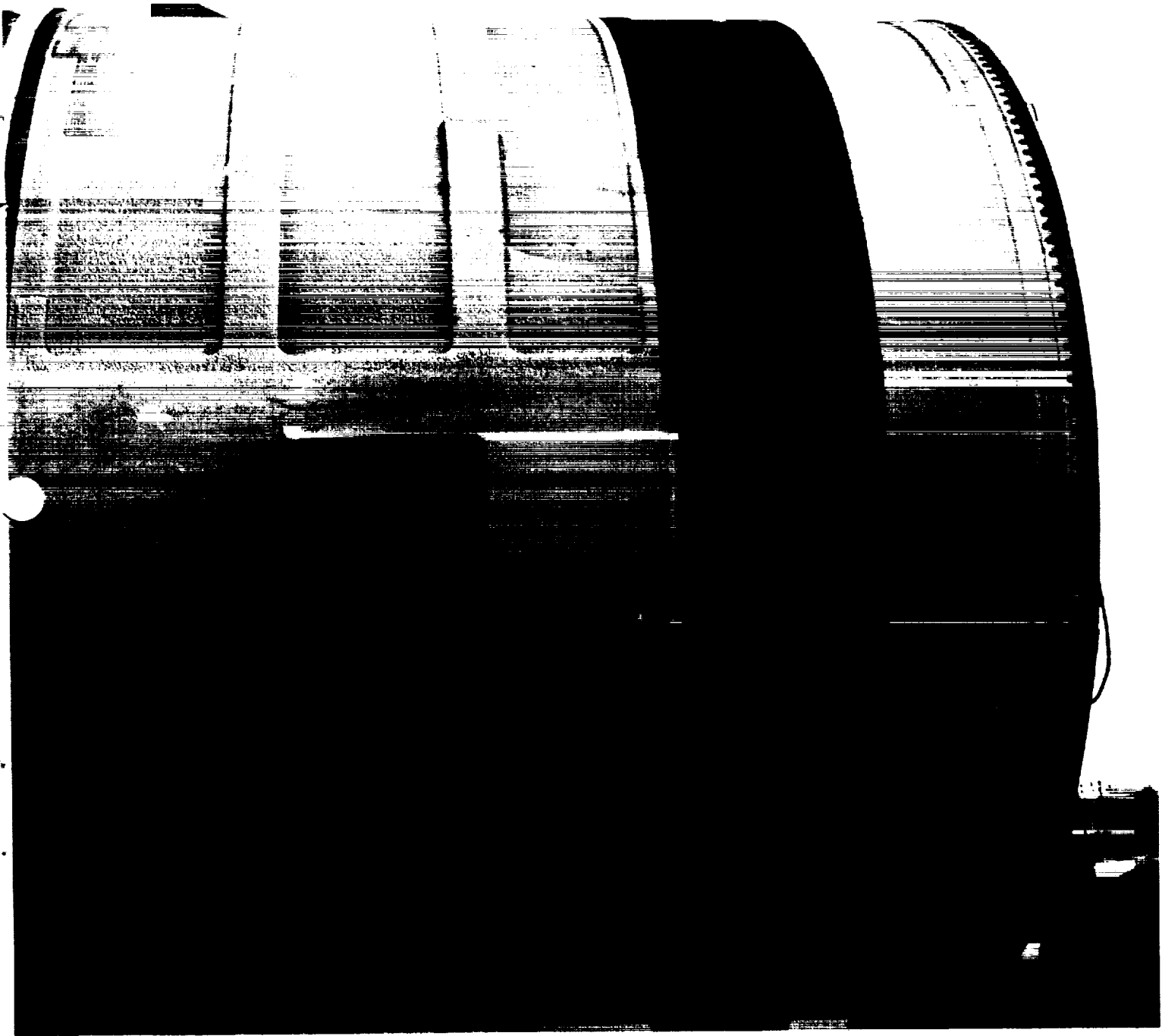


The LH frustum was missing no TPS, but had a total of 11 MSA-2 debonds over fasteners. All BSM aero heatshield covers had locked in the fully opened position, though the upper right cover attach ring had been bent by parachute riser entanglement



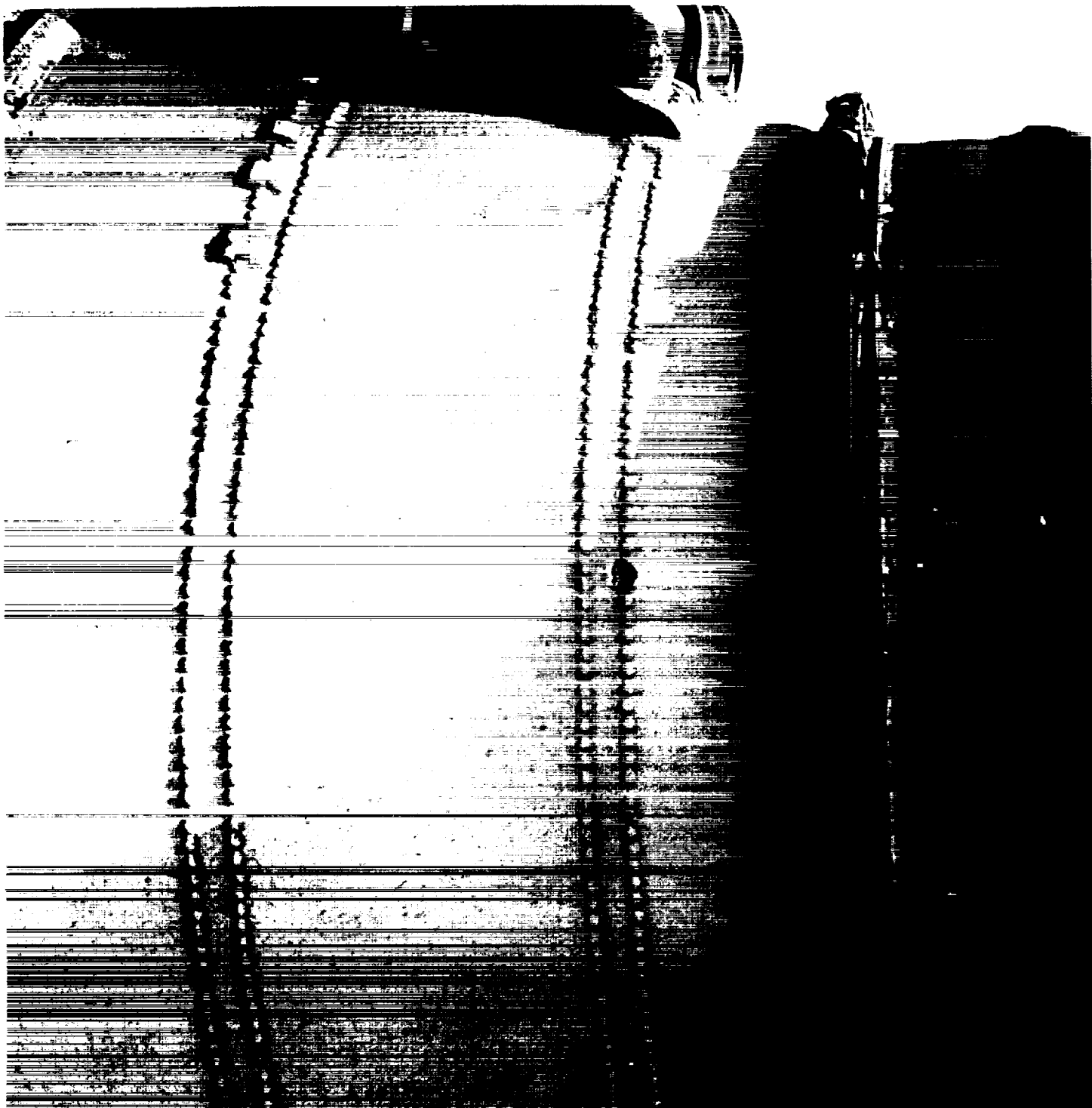


Preliminary post flight assessment revealed the upper right BSM aero heat shield cover had opened and locked properly. The cover was bent back to the 90 degree position. The fracture plane on the cover attach ring was not sooted and may indicate the failure occurred late in re-entry or at water splashdown.



The LH forward skirt acreage MSA-2 exhibited no debonds or missing TPS. Both RSS antenna covers/phenolic base plates were intact.





Aft skirt acreage TPS was generally in good condition though MSA-2 was missing from four places on the 1860 ring frame and near the HDP #7 foot. No significant amount of BTA was used on this aft skirt.



7.0 ORBITER POST LANDING DEBRIS ASSESSMENT

A post landing debris inspection of OV-103 (Discovery) was conducted 11-14 February at the Kennedy Space Center on Shuttle Landing Facility (SLF) runway 15 and in the Orbiter Processing Facility bay #3. This inspection was performed to identify debris impact damage and, if possible, debris sources. The Orbiter TPS sustained a total of 106 hits, of which 15 had a major dimension of one inch or greater. This total does not include the numerous hits on the base heat shield attributed to SSME vibration/acoustics and exhaust plume recirculation. A comparison of these numbers to statistics from 44 previous missions of similar configuration (excluding missions STS-23, 25, 26, 26R, 27R, 30R, and 42, which had damage from known debris sources), indicates both the total number of hits and the number of hits 1-inch or larger was less than average (reference Figures 8-11).

The following table breaks down the STS-60 Orbiter debris damage by area:

	<u>HITS > 1"</u>	<u>TOTAL HITS</u>
Lower surface	4	48
Upper surface	1	28
Right side	0	2
Left side	0	4
Right OMS Pod	2	7
Left OMS Pod	8	17
TOTALS	15	106

The Orbiter lower surface sustained a total of 48 hits, of which 4 had a major dimension of 1-inch or greater. The distribution of hits on the lower surface does not suggest a single source of ascent debris, but indicates a shedding of ice and Thermal Protection System (TPS) debris from random sources.

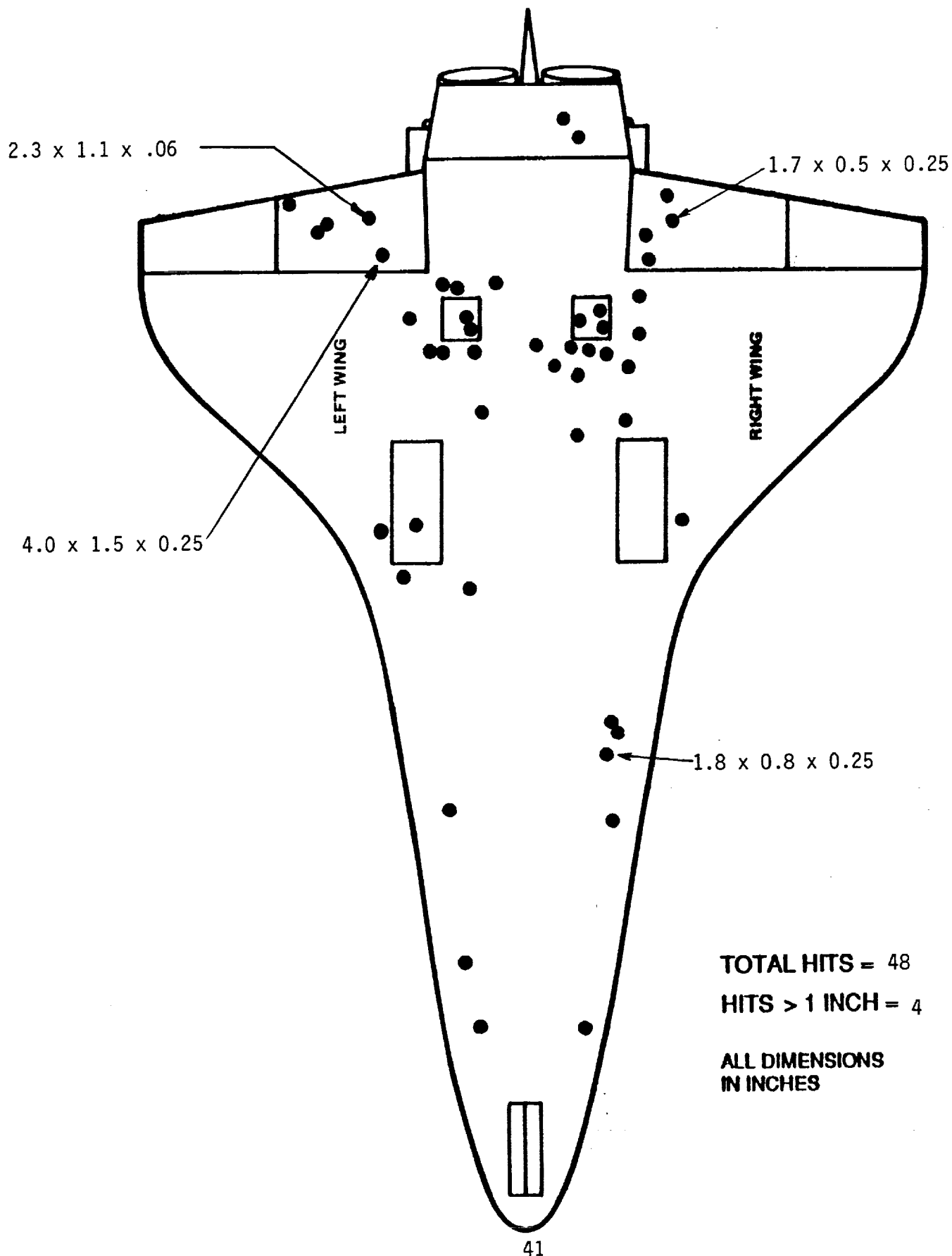
The largest tile damage site measured 4.0" x 1.5" x 0.25" and was located on the left inboard elevon. The remaining tile material in the damage site showed no significant signs of heating, glazing, erosion, etc.

A greater than usual number of tile damage sites occurred on the leading edges of the OMS pods and vertical stabilizer. Eleven of these hits had a major dimension larger than 1-inch. Depths ranged from 1/8 to 3/4 inches. This type of damage is usually attributed to impacts from higher density material, such as ice from the waste water dump.

Clusters of hits near the LH2 and LO2 ET/ORB umbilicals may be indicative of impacts from umbilical ice.

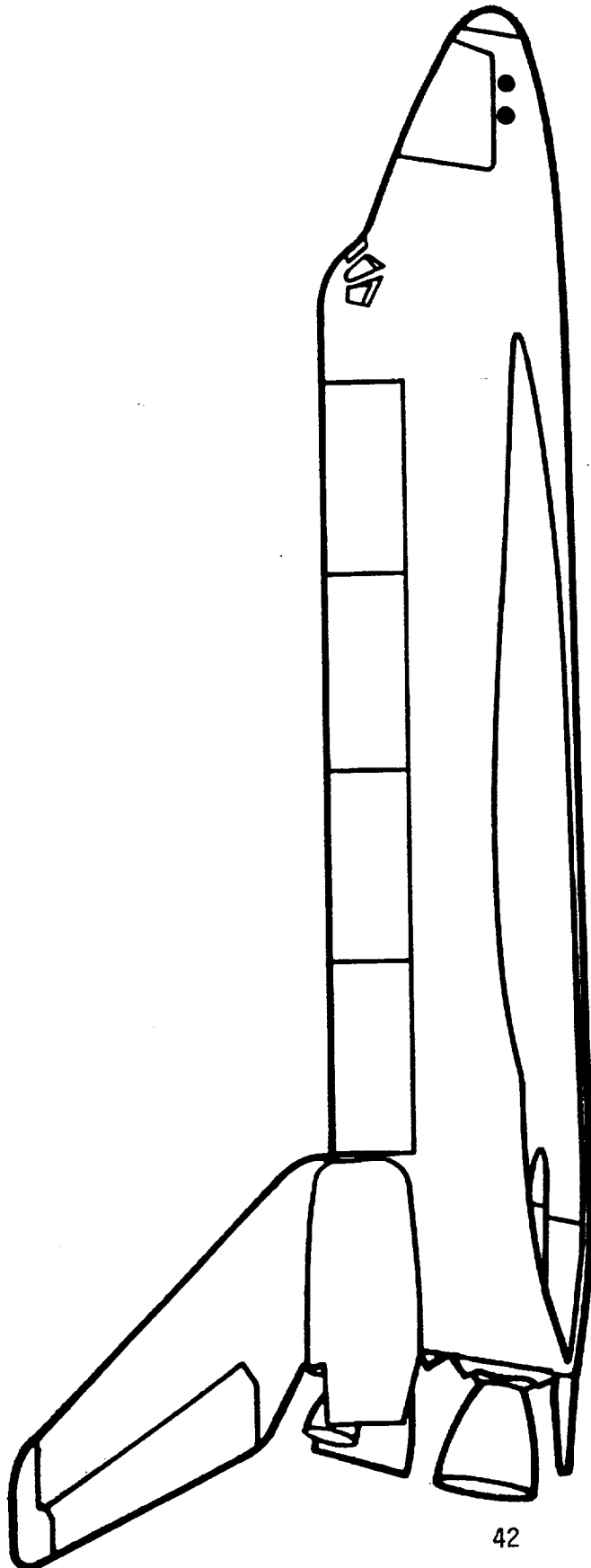
STS-60

FIGURE 8. **DEBRIS DAMAGE LOCATIONS**



STS-60

FIGURE 9. **DEBRIS DAMAGE LOCATIONS**

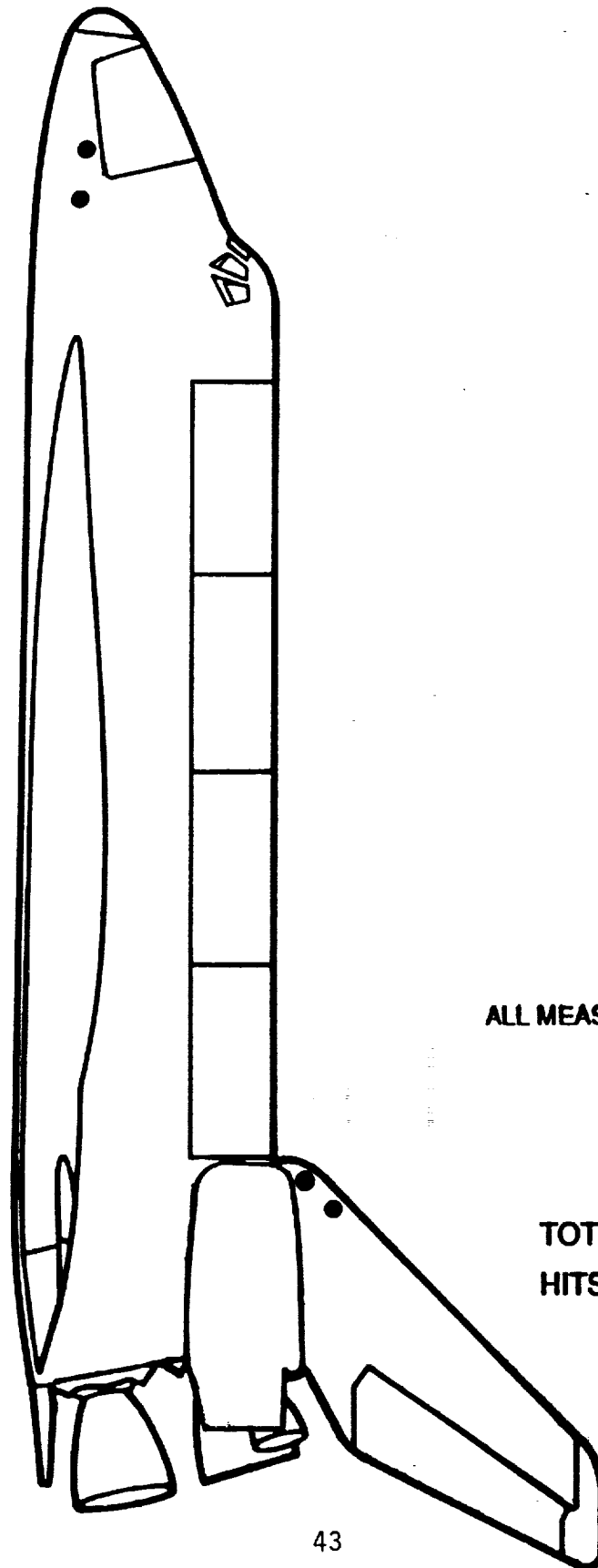


TOTAL HITS = 2

HITS > 1 INCH = 0

STS-60

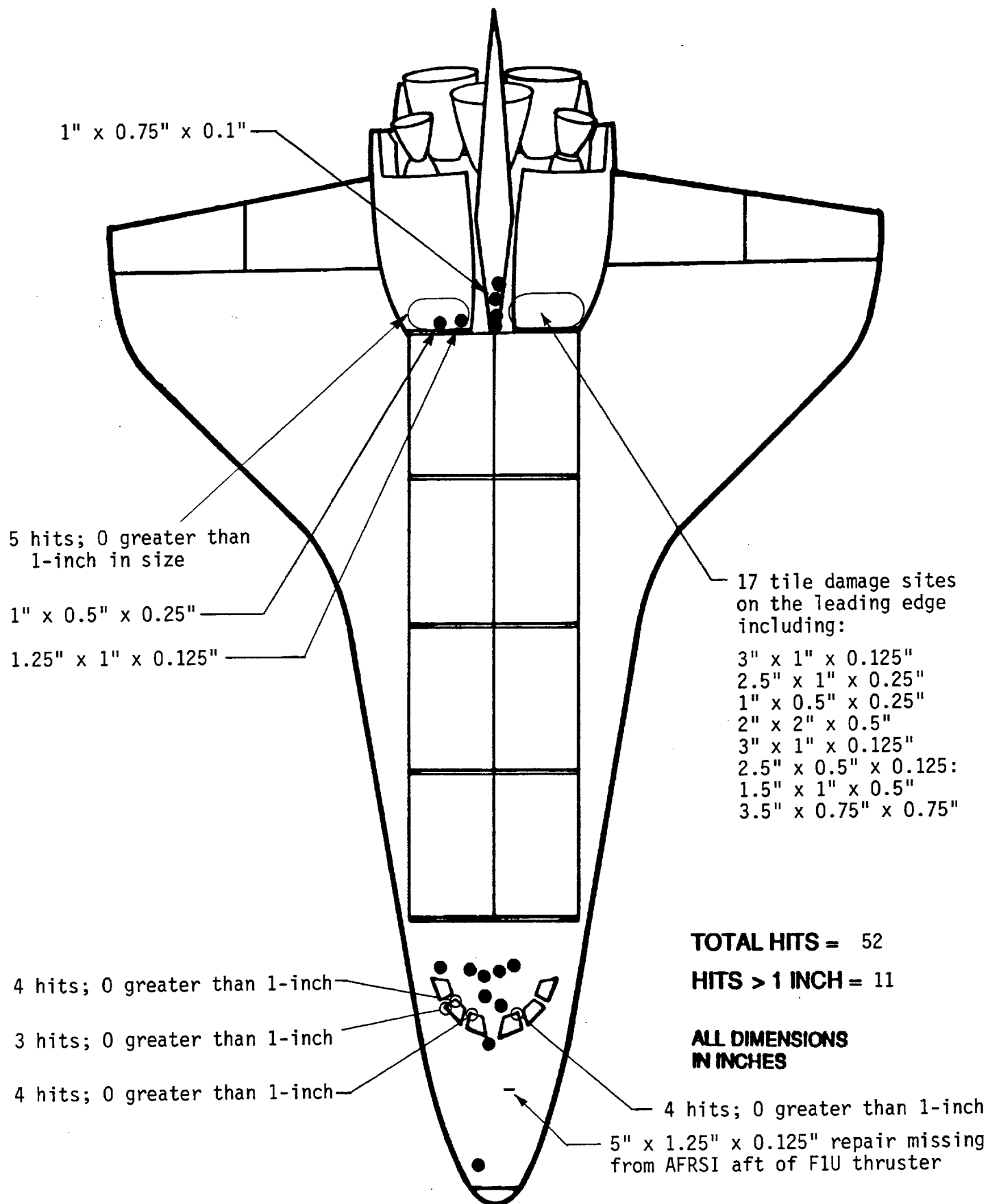
FIGURE 10. **DEBRIS DAMAGE LOCATIONS**



ALL MEASUREMENTS IN INCHES

TOTAL HITS = 4

HITS > 1 INCH = 0

FIGURE 11. **DEBRIS DAMAGE LOCATIONS**

No tile damage from micrometeorites or on-orbit debris was identified during the inspection.

White residue/deposits were visible on the RH wing T-seal #9.

No TPS damage was attributed to material from the wheels, tires, or brakes. The tires were in good condition after a landing on the KSC runway.

ET/Orbiter separation devices EO-1, EO-2, and EO-3 functioned properly. All ET/Orbiter umbilical separation ordnance retention shutters were closed. No significant amounts of foam or red purge seal adhered to the LH2 ET/ORB umbilical near the 4-inch flapper valve. The shim in the EO-2 "salad bowl" was partially debonded and displaced across the stud hole approximately 1/4-inch. No debris was found on the runway beneath the ET/ORB umbilical cavities.

Orbiter windows #3 and #4 exhibited moderate hazing with some streaks. Only a very light haze was present on the other windows. Surface wipes will be taken from all windows for laboratory analysis. No other sites on the Orbiter were identified for chemical analysis sampling. Tile damage on the window perimeter tiles was typical.

Tile damage on the base heat shield was also typical. The Dome Mounted Heat Shield (DMHS) closeout blankets on all three SSME's were in excellent condition and no material was missing. Minor fraying occurred at the 7:00 o'clock position on the SSME #1 DMHS blanket. Tiles on the vertical stabilizer "stinger" and around the drag chute door were intact and undamaged.

Runway 15 had been swept/inspected by SLF operations personnel prior to landing and all potentially damaging debris was removed.

The post landing walkdown of Runway 15 was performed immediately after landing. No unexpected flight hardware was found on the runway. All Orbiter drag chute hardware was recovered and showed no signs of abnormal operation. No organic (bird) debris was found on the runway.

The Shuttle Thermal Imager (STI) was used to measure the surface temperatures of several areas on the vehicle (per OMRSD V09AJ0.095). Twenty-four minutes after landing, the Orbiter nose cap RCC was 170 degrees Fahrenheit. Twenty-seven minutes after landing, the RH wing leading edge RCC panel #9 was 104 degrees F and panel #17 was 99 degrees F (Figure 12).

In summary, both the total number of Orbiter TPS debris hits and the number of hits 1-inch or larger was less than average when compared to previous missions (reference Figures 13-14). Orbiter Post Launch Debris Anomalies are listed in Section 9.

FIGURE 12. **STS-60 RCC TEMPERATURE MEASUREMENTS AS
RECORDED BY THE SHUTTLE THERMAL IMAGER**

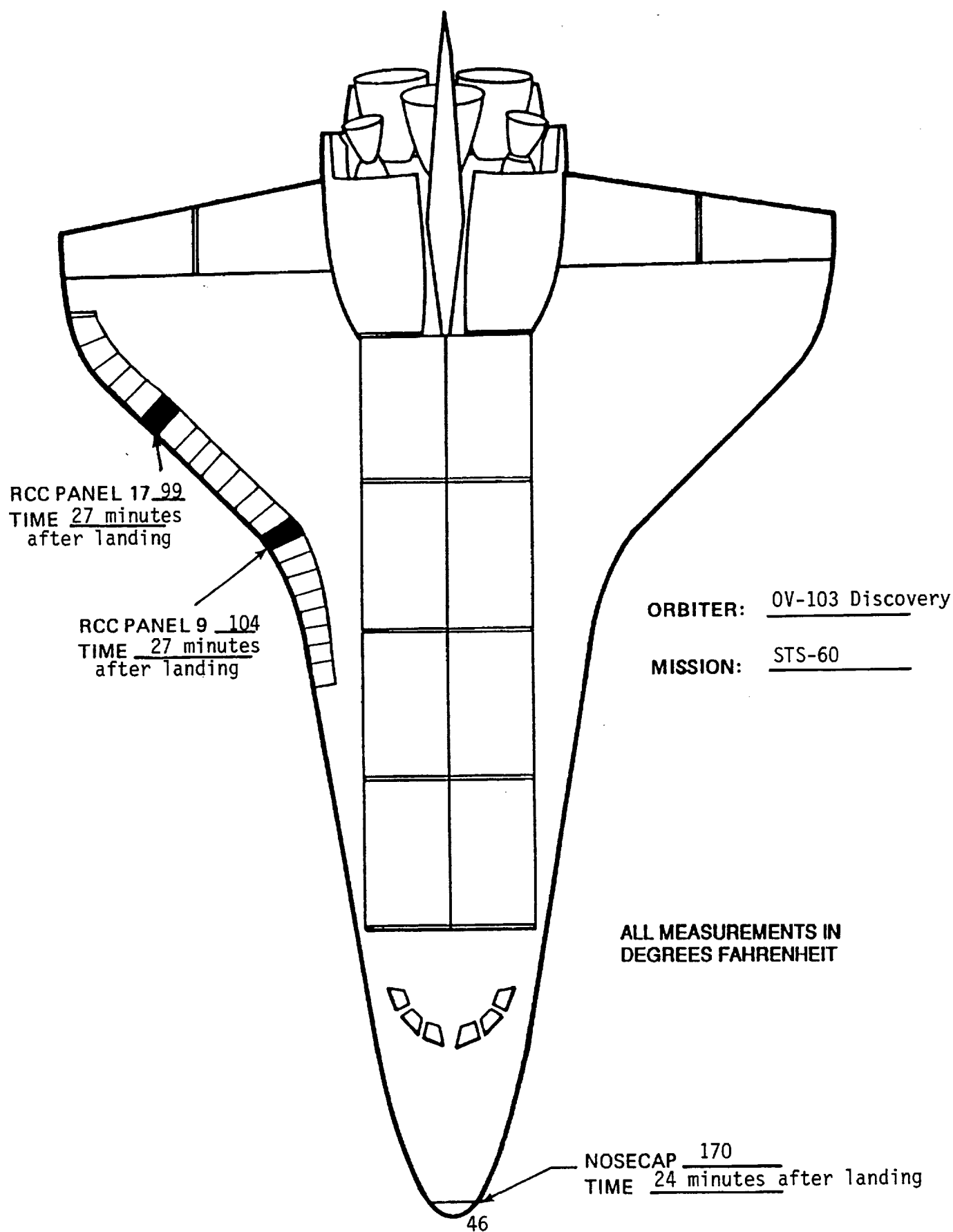


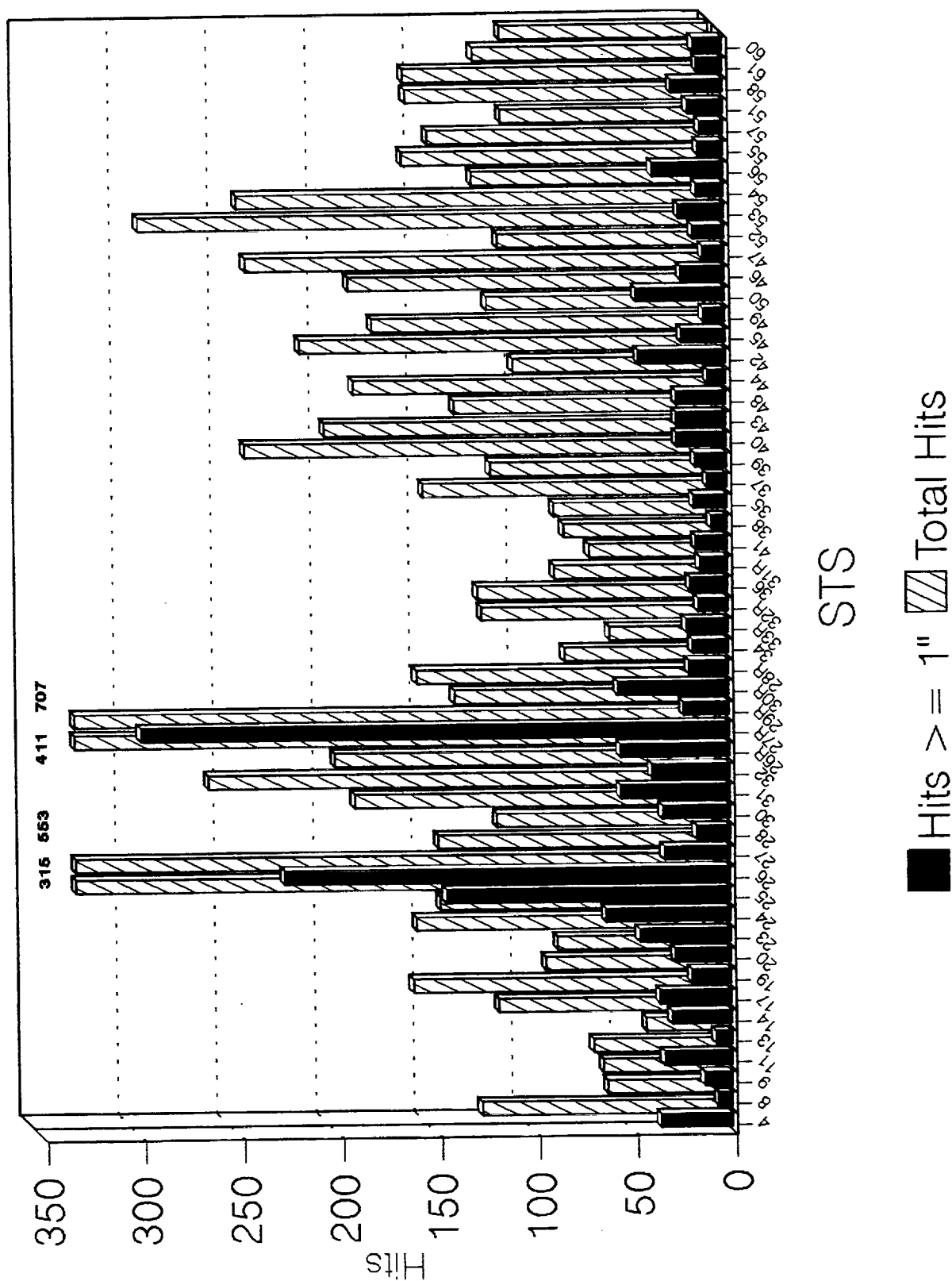
FIGURE 13 ORBITER POST FLIGHT DEBRIS DAMAGE SUMMARY

	LOWER SURFACE		ENTIRE VEHICLE	
	HITS > 1 INCH	TOTAL HITS	HITS > 1 INCH	TOTAL HITS
STS-6	15	80	36	120
STS-8	3	29	7	56
STS-9 (41-A)	9	49	14	58
STS-11 (41-B)	11	19	34	63
STS-13 (41-C)	5	27	8	36
STS-14 (41-D)	10	44	30	111
STS-17 (41-G)	25	69	36	154
STS-19 (51-A)	14	66	20	87
STS-20 (51-C)	24	67	28	81
STS-27 (51-I)	21	96	33	141
STS-28 (51-J)	7	66	17	111
STS-30 (61-A)	24	129	34	183
STS-31 (61-B)	37	177	55	257
STS-32 (61-C)	20	134	39	193
STS-29	18	100	23	132
STS-28R	13	60	20	76
STS-34	17	51	18	53
STS-33R	21	107	21	118
STS-32R	13	111	15	120
STS-36	17	61	19	81
STS-31R	13	47	14	63
STS-41	13	64	16	76
STS-38	7	70	8	81
STS-35	15	132	17	147
STS-37	7	91	10	113
STS-39	14	217	16	238
STS-40	23	153	25	197
STS-43	24	122	25	131
STS-48	14	100	25	182
STS-44	6	74	9	101
STS-45	18	122	22	172
STS-49	6	55	11	114
STS-50	28	141	45	184
STS-46	11	186	22	236
STS-47	3	48	11	108
STS-52	6	152	16	290
STS-53	11	145	23	240
STS-54	14	80	14	131
STS-56	18	94	36	156
STS-55	10	128	13	143
STS-57	10	75	12	106
STS-51	8	100	18	154
STS-58	23	78	26	155
STS-61	7	59	13	120
AVERAGE	14.4	92.6	21.7	133.4
SIGMA	7.3	44.1	10.6	58.5
STS-60	4	48	15	106

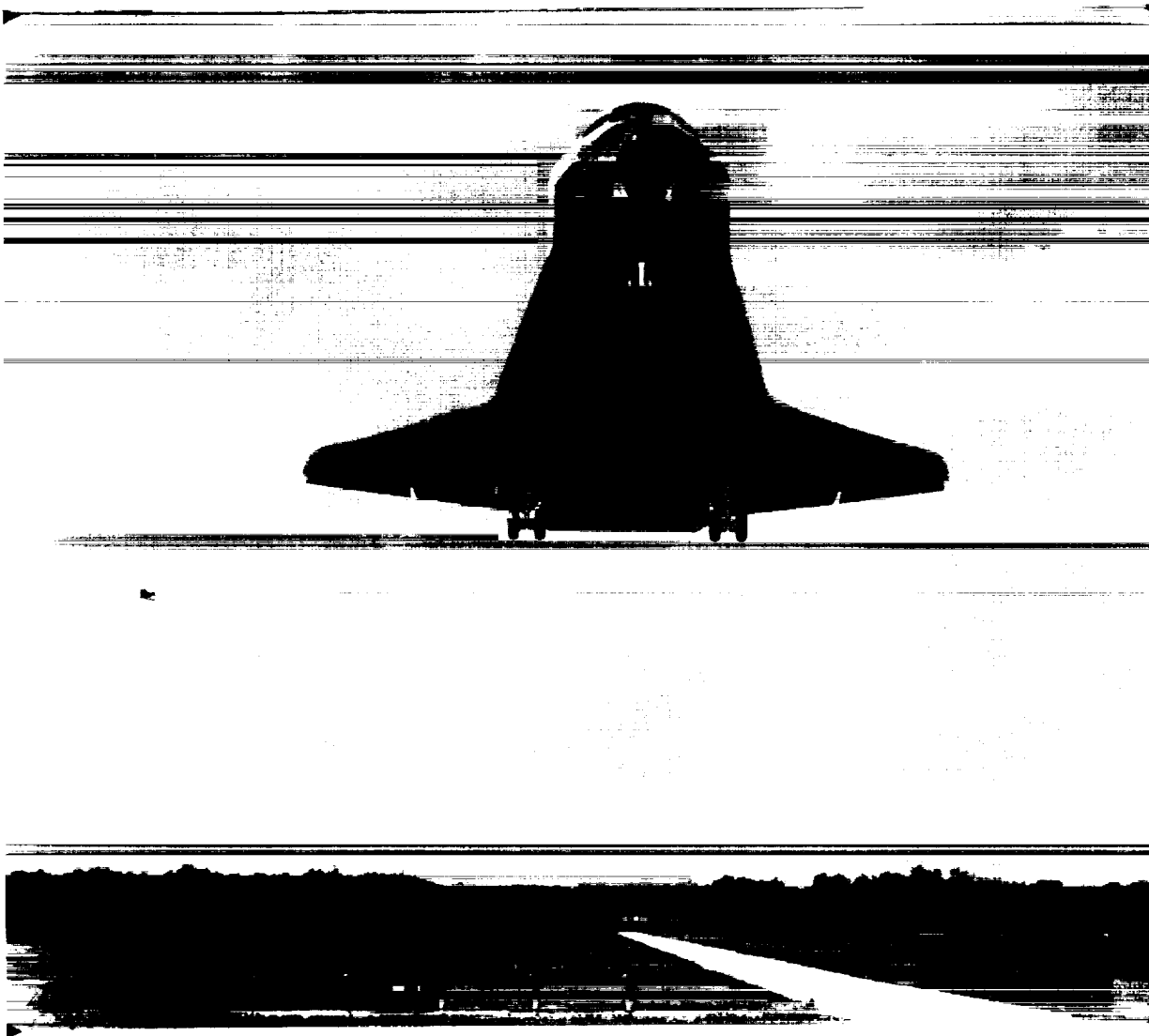
MISSIONS STS-23, 24, 25, 26, 26R, 27R, 30R, AND 42 ARE NOT INCLUDED IN THIS ANALYSIS
SINCE THESE MISSIONS HAD SIGNIFICANT DAMAGE CAUSED BY KNOWN DEBRIS SOURCES

COMPARISON TABLE

FIGURE 14.







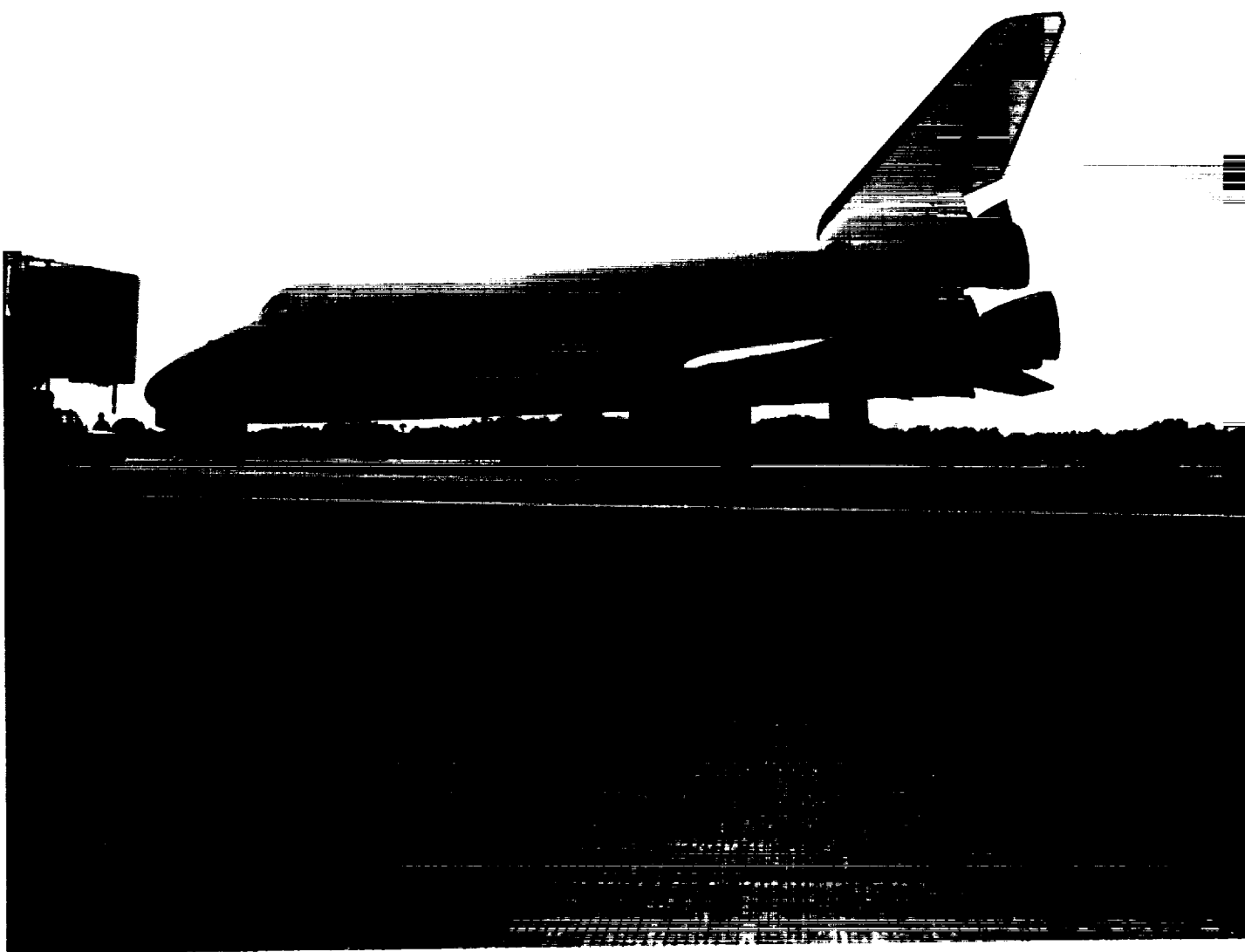
OV-103 Discovery landed on Kennedy Space Center SLF
runway 33 on 11 February 1994





Overall view of the Orbiter right side





Overall view of Orbiter left side



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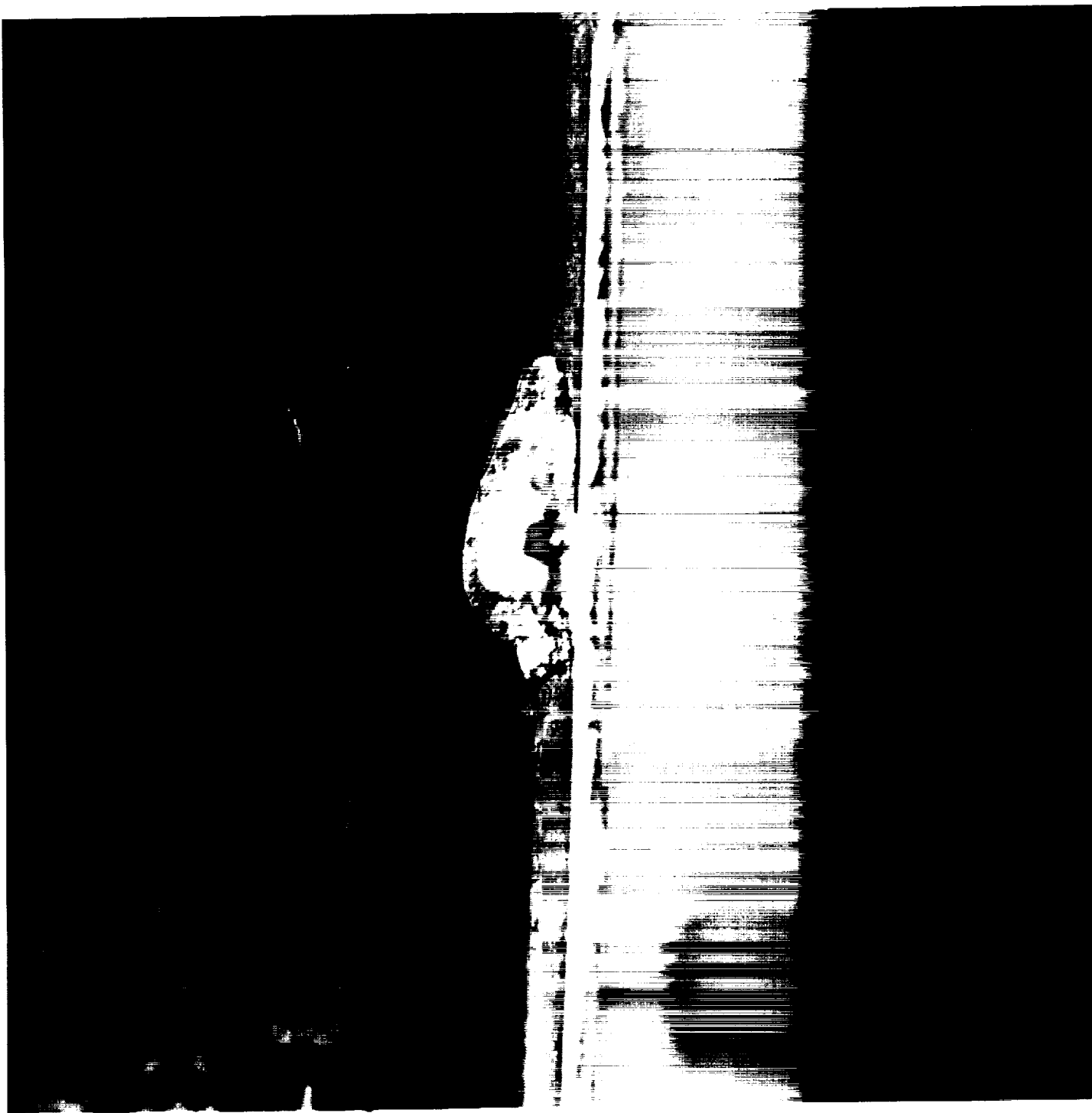
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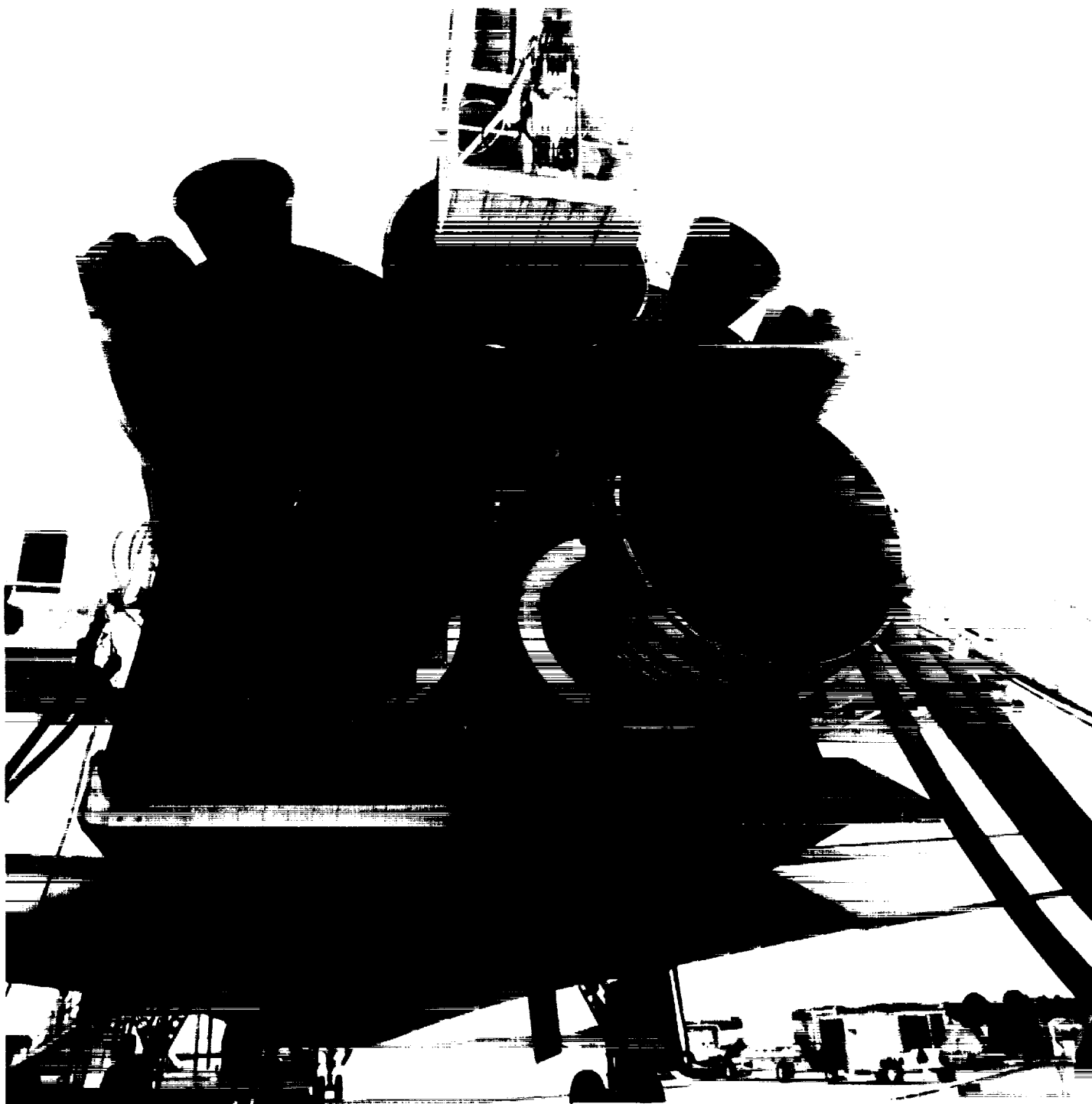
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Tile damage on ET/ORB umbilical door leading edge



Overall view of SSME's and base heat shield. The SSME DMHS closeout blankets were in excellent condition. The Orbiter lower surface tiles sustained a total of 48 hits, of which 4 had a major dimension of 1-inch or greater.



11

12

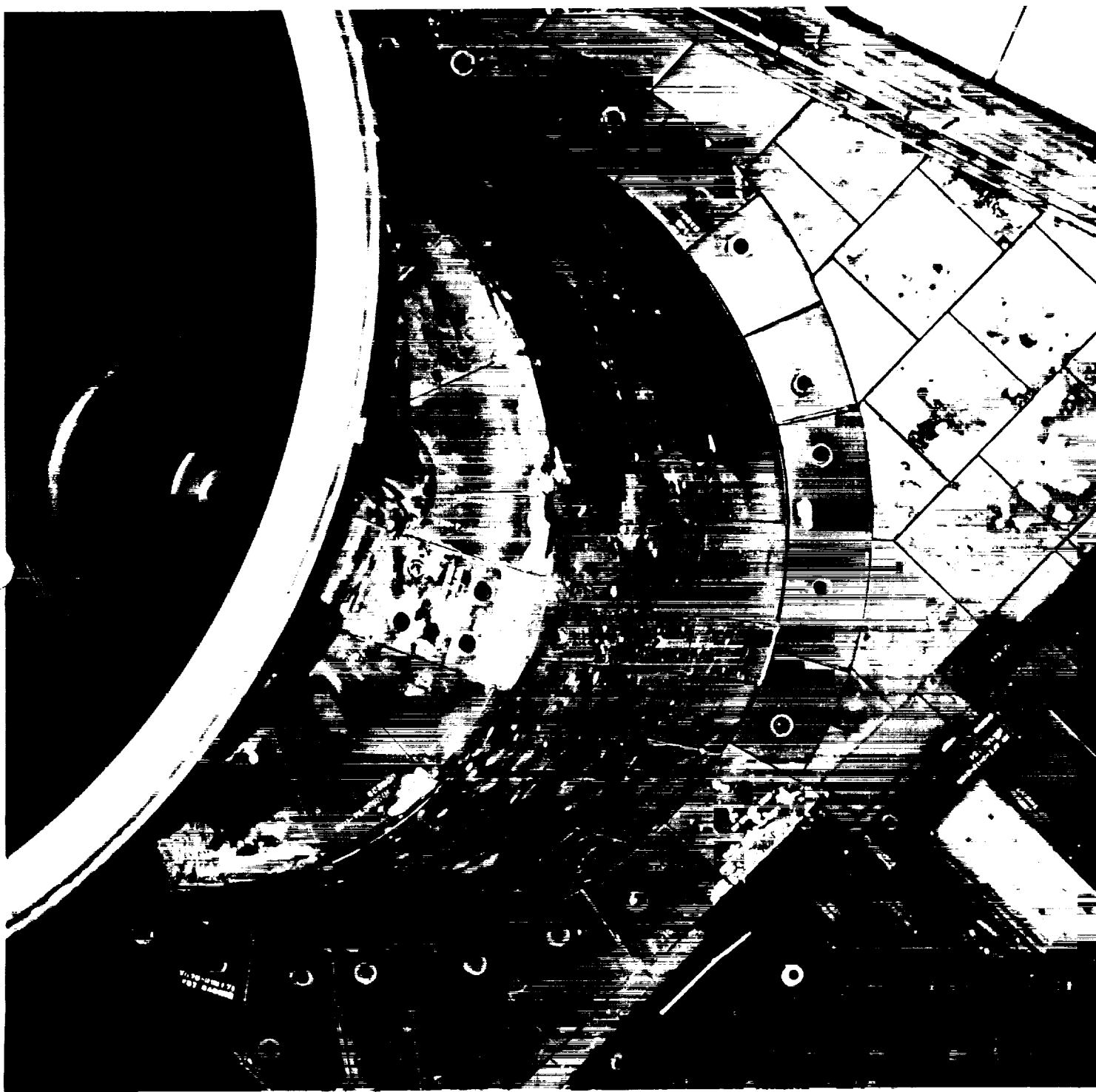


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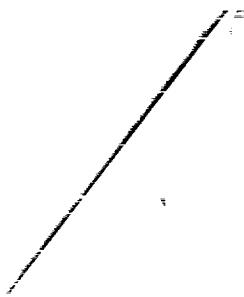
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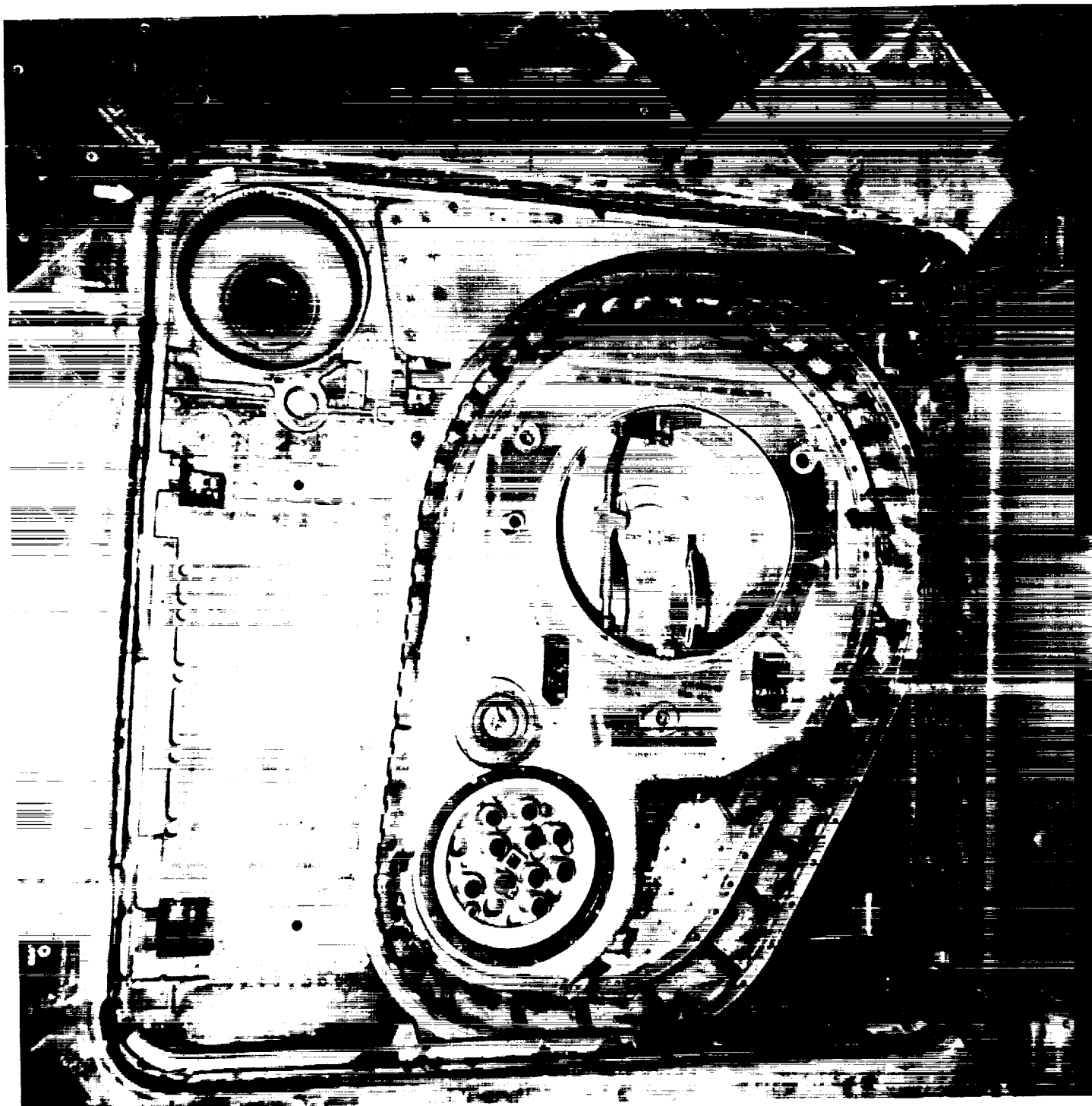


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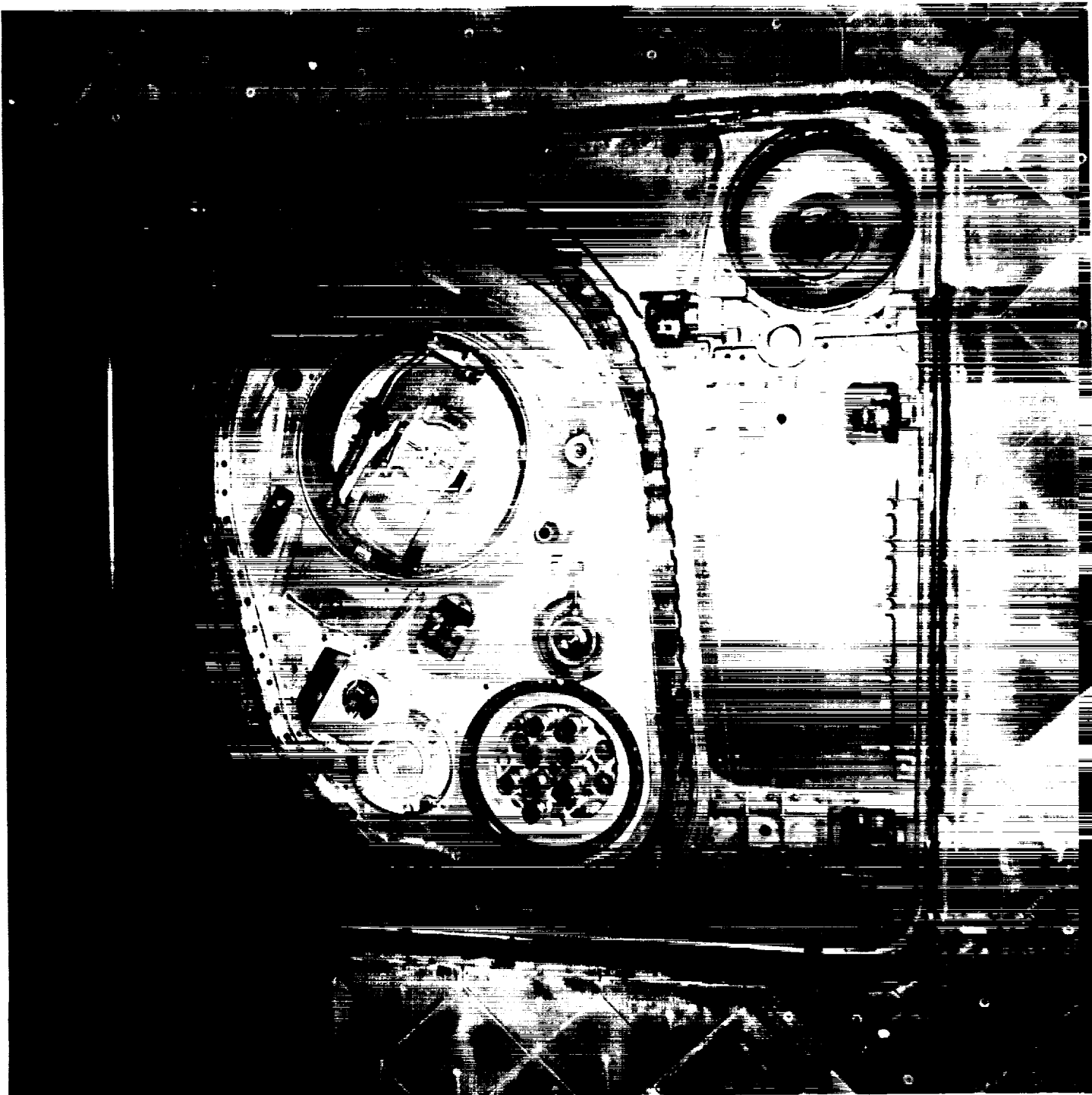


Tile surface coating material was lost from numerous places
on the base heat shield and RH OMS nozzle heat shield





Overall view of the LO2 ET/ORB umbilical. All separation ordnance devices functioned properly. No flight hardware was found on the runway below the umbilical when the ET door was opened.



Overall view of the LH2 ET/ORB umbilical. All separation ordnance devices functioned properly. No flight hardware was found on the runway below the umbilical when the ET door was opened.



1

2



3

4





The shim in the EO-2 "salad bowl" was partially debonded and displaced across the stud hole approximately 1/4 inch



1

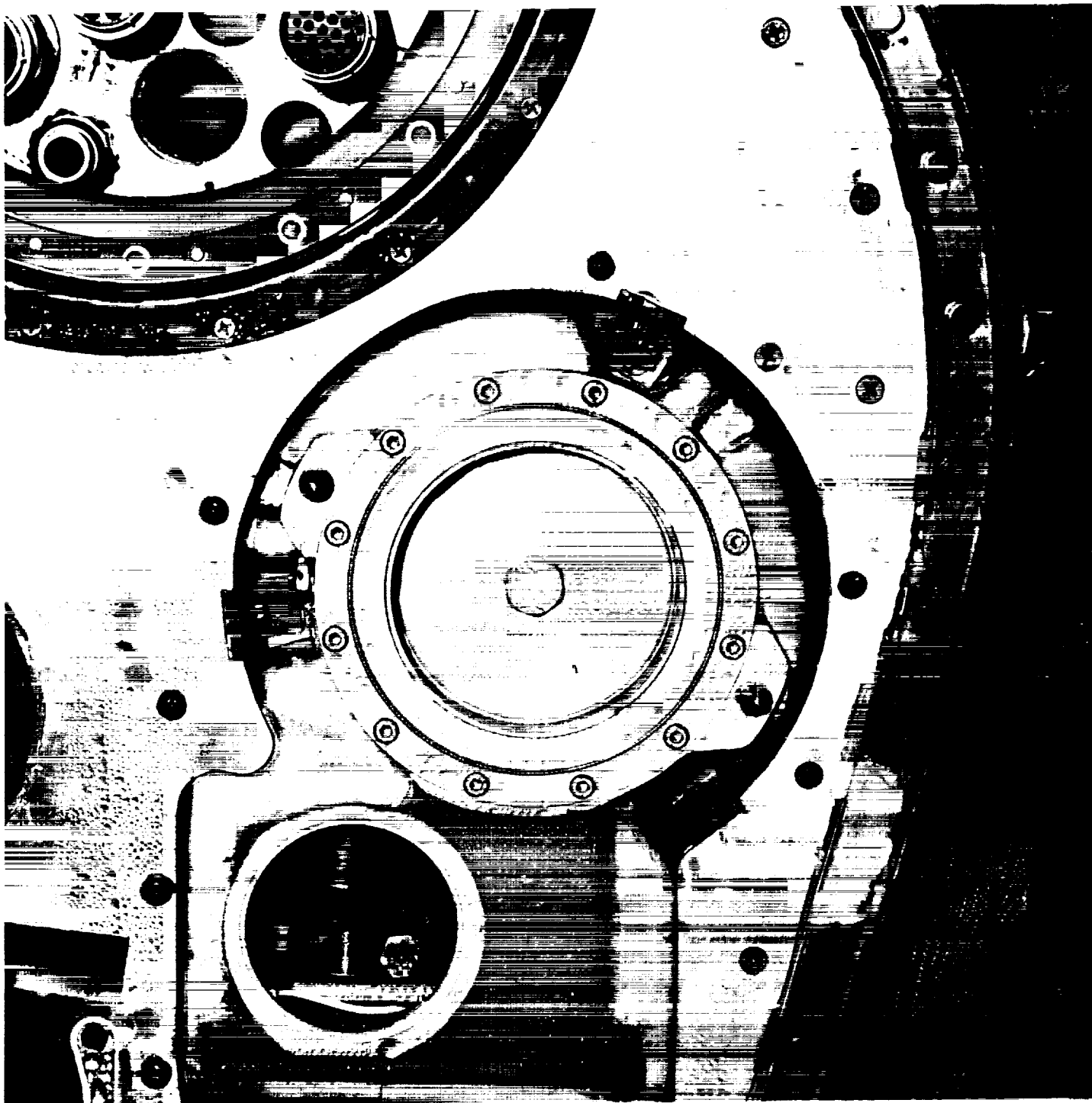
2



3

4





No significant amounts of ET foam or red purge seal adhered to the LH2 ET/ORB umbilical plate near the LH2 4-inch line flapper valve.



7

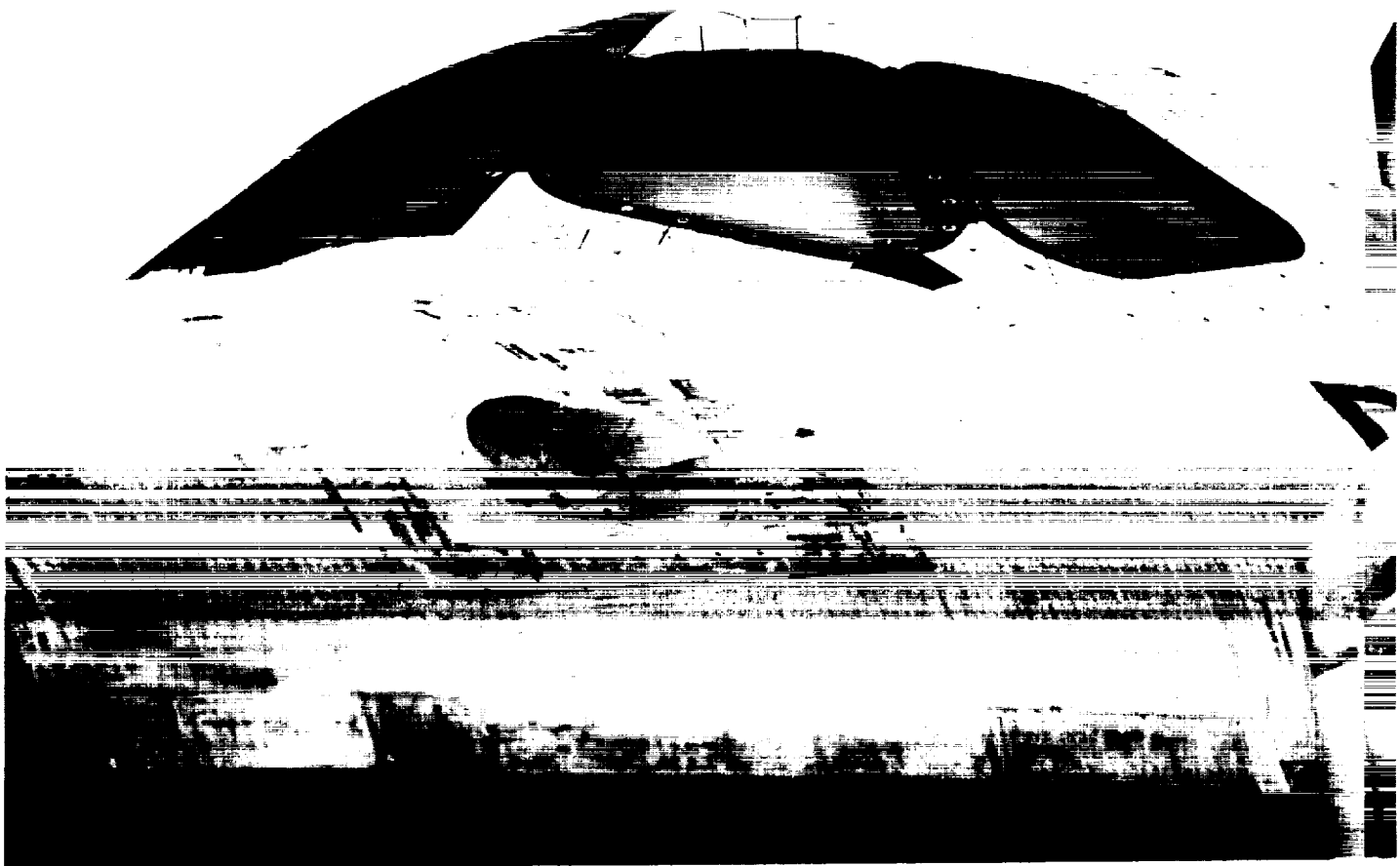
8



9

10





Orbiter windows #3 and #4 were moderately hazed and some streaks were present. Damage to window perimeter tiles was typical.



8.0 DEBRIS SAMPLE LAB REPORTS

A total of eight samples were obtained from OV-103 Discovery during the STS-60 post landing debris assessment at Kennedy Space Center. The samples consisted of 16 wipes from Orbiter windows #1 - #8. The samples were analyzed by the NASA KSC Microchemical Analysis Branch (MAB) for material composition and comparison to known STS materials. Debris analysis involves placing and correlating of particles and residues with respect to composition, thermal (mission) effects, and availability. Debris sample results/analyses are listed by Orbiter location in the following summaries.

ORBITER WINDOWS

Samples from the Orbiter windows indicated exposure to SRB BSM exhaust, Orbiter Thermal Protection System (TPS), paints and primer from various sources, and natural landing site products. Textile and building insulation fibers were also present. All of these materials have been previously observed and occurred only in trace quantities. There was no apparent vehicle damage related to these residuals.

STS-60 ORGANIC ANALYSIS

The final results of the STS-60 organic analysis are pending. Documentation will be included in a subsequent report.

NEW FINDINGS

No new findings were noted in these inorganic sample results (Figure 15). Final results that include the organic analyses will be evaluated for documentation in a subsequent report.

STS	Sample Location			
	Windows	Wing RCC	Lower Tile Surface	Other
60	Metallics - BSM Residue (SRB) RTV, Tile, Tile filler (ORB TPS) Insulation Glass (ORB TPS) Fiber - Building Insulation, textile Earth minerals - (Landing site) Organics Paint and primer			
61	Metallics - BSM Residue (SRB) RTV, Tile filler (ORB TPS) Insulation Glass (ORB TPS) Fiber - Building Insulation, textile Earth minerals - (Landing site) Blue paint particles Organics - Plastic polymers, rubber RTV-RCS Nozzle thruster cover(SRB) Paint and primer			
51	Metallics - BSM Residue (SRB) - Solder (Launch Site) RTV, Tile, Tile coating (ORB TPS) Insulation Glass (ORB TPS) Glass fiber 'E-glass' Organics-Plastic polymer, filled plastic(PVC) Paint		Silica tile material Black and white paints Organics - Plastic polymer, RTV, paint	Left OMS pod- tile, RTV, silicon carbide
57	Metallics-BSM Residue(SRB) RTV, Tile, Tile coating(ORB TPS) Insulation Glass(ORB TPS) Glass fiber-"E"-glass Calcite, Alpha-Quartz, Salt(Landg. Site) Paint and Primer Organics-plastic polymer, RTV, paint			
55	Metallics - BSM Residue (SRB) RTV, Tile (ORB TPS) Insulation Glass (ORB TPS) Glass fiber - 'E-glass' Calcite, Muscovite, Salt(Landing Site) Anhydrite (Landing Site) Paint Organics-Plastic polymer, rubber, adh.			
56	Metallics - BSM Residue (SRB) - Solder (Launch Site) RTV, Tile, Tile coating (ORB TPS) Insulation Glass (ORB TPS) Glass fiber 'E-glass' Organics-Plastic polymer, filled plastic(PVC) Paint		Silica-rich tile (ORB TPS) Tile coating, RTV (ORB TPS)	

FIGURE 15. Orbiter Post Landing Microchemical Sample Results

STS	Sample Location				
	Windows	Wing RCC	Lower Tile Surface	Umbilical	Other
54	Metallics - BSM Residue (SRB) RTV, Tile (ORB TPS) Insulation Glass (ORB TPS) Calcite, Alpha-Quartz, Salt (Lndg. Site) Organics - plastic (locite) Organics-Plastic polymer, filled plastic (PVC) Paint	Metallics - BSM Residue (SRB) Tile, Insulation Glass (ORB TPS) Calcium - Silica, Salt (Landing Site) Organics - plastic polymers Paint			
53	Metallics - BSM Residue (SRB) - Solder (Launch Site) RTV, Tile (ORB TPS) Insulation Glass (ORB TPS) Calcite, Salt (Landing Site) Organics - Fibrous mat'l, RTV, Grease Organics-filled rubber, plastic polymers Paint			LO2 Umbilical Door - - Closeout Mat'l (ORB TPS) - Hydrocarbon "grease-like" sub.	RH SRB Air Skirt Damage site - - Tile, Tile coating mat'l (ORB TPS)
52	Metallics - BSM Residue (SRB) RTV, Tile (ORB TPS) Insulation Glass (ORB TPS) Calcite, Salt (Landing Site) Organics-Fibrous mat'l, red RTV Organics-filled rubber, plastic polymers Paint				HRSI Tile Damage Site- - Tile Mat'l and silicon carbide (ORB TPS) - Paints - Calcite, salts (Landing Site)
47	Metallics - BSM Residue (SRB) RTV, Tile (ORB TPS) Insulation Glass (ORB TPS) Calcite, Salt (Landing Site) Window Polish Residue (ORB) Organics-Fibrous mat'l, red RTV Organics-filled rubber, plastic polymers Paint		Silica-rich Tile (ORB TPS)		
46	Metallics - BSM Residue (SRB) RTV, Tile (ORB TPS) Insulation Glass (ORB TPS) Calcite, Alpha-Quartz, Salt (Lndg. Site) Organics-Adhesive, Foam, red RTV Organics-filled rubber, plastic polymers Paint				Crew Hatch Window - Metallics - BSM Residue (SRB) - Alpha-Quartz, Salt (Landing Site) - RTV, Tile (ORB TPS) - Paint - Organics
50	Metallics - BSM Residue (SRB) RTV, Tile (ORB TPS) Insulation Glass (ORB TPS) Window Polish Residue (ORB) Mica, Calcium, Salt (Landing Site) Organics-Adhesive, Foam Organics-Plastic Polymers Paint		Silica-Rich Tile (ORB TPS)		Orbiter Vertical Stabilizer - Tile Coating (ORB TPS) - Structural Coating Glass "E-Glass"

FIGURE 15. Orbiter Post Landing Microchemical Sample Results

STS	Sample Location			
	Windows	Wing RCC	Lower Tile Surface	Other
49	Metallics - BSM Residue (SRB) RTV, Tile (ORB TPS) Insulation Glass (ORB TPS) Mica, Calcium, Salt (Landing Site) Organics Paint	RTV, Tile (ORB TPS) Rust - BSM Residue (SRB) Muscovite, Salt (Landing Site) Organics Paint	RTV, Tile (ORB TPS) Insulation Glass (ORB TPS) Rust - BSM Residue (SRB) Calcium Mat, Salt (Landing Site Soil) Organics Paint	
45	Metallics - BSM Residue (SRB) RTV, Tile (ORB TPS) Insulation Glass (ORB TPS) Calcite, Salt (Landing Site) Window Polish Residue (ORB) Organics Paint		Iron - Rich Mat Paint	
42	Metallics - BSM Residue (SRB) RTV, Tile (ORB TPS) Insulation Glass (ORB TPS) Calcite, Salt (Landing Site) Muscovite (Landing Site) Organics Paint		Metallics - BSM Residue (SRB) Tile, Tile Coating (ORB) Salt (Landing Site) Paint	Organics RH Fuelage - Tile Coating (ORB)
44	Metallics - BSM Residue (SRB) RTV, Tile (ORB TPS) Insulation Glass (ORB TPS) Calcite, Salt (Landing Site) Muscovite (Landing Site) Organics Paint			Organics Silica-Magnesium Mat
48	Metallics - BSM Residue (SRB) RTV, Tile (ORB TPS) Insulation Glass (ORB TPS) Calcite, Salt (Landing Site) Muscovite (Landing Site) Organics Paint			Metallics Silica - Rich Mat (Landing Site) On Umbilical CO Mat (ORB) Paints
43	Metallics - BSM Residue (SRB) RTV, Tile (ORB TPS) Insulation Glass (ORB TPS) Calcite, Salt (Landing Site) Window Polish Residue (ORB) Organics Paint		RTV, Tile (ORB TPS) Metallics - BSM Residue (SRB) Salt (Landing Site) Organics Paint	Runway - FRSI Coating (ORB)
40	Metallics - BSM Residue (SRB) RTV, Tile (ORB TPS) Insulation Glass (ORB TPS) Calcite, Salt (Landing Site) Window Polish Residue (ORB) Organics Paint	Metallics - BSM Residue (SRB) RTV, Tile (ORB) Insulation Glass (ORB TPS) Eucalyptus Foam (RCC Prod. Covers) Organics Paint	RTV, Tile (ORB TPS)	Metallics - BSM Residue (SRB) RTV, Tile (ORB TPS) Insulation Glass (ORB TPS) Organics (ORB Umb CO) Paint

FIGURE 15. Orbiter Post Landing Microchemical Sample Results

STS	Sample Location				
	Windows	Wing RCC	Lower Tile Surface	Unbonded	Other
39		Metallics - BSM Residue (SRB) RTV, Tile (ORB) Insulation Glass (ORB TPS) Eneclite Foam (RCC Prot. Covers) Organics Paint Hypalon Paint (SRB)	Tile (ORB TPS) Insulation Glass (ORB TPS)		
37	Metallics - BSM Residue (SRB) RTV, Tile (ORB TPS) Insulation Glass (ORB TPS) Calcite, Salt (Landing Site) Organics	Metallics - BSM Residue (SRB) RTV, Tile (ORB) Insulation Glass (ORB TPS) Calcite, Salt (Landing Site) Organics Paint	RTV, Tile (ORB TPS) Insulation Glass (ORB TPS) Metallics - BSM Residue (SRB) Calcite, Salt (Landing Site) Organics		
35	Metallics - BSM Residue (SRB) RTV, Tile (ORB TPS) Insulation Glass (ORB TPS) Calcite, Salt (Landing Site) Window Polish Residue (ORB) Organics Paint	Metallics - BSM Residue (SRB) RTV, Tile (ORB) Organics	RTV, Tile (ORB TPS) Metallic - Rust, Aluminum Welding Slag (Facility)		
38		RTV, Tile (ORB TPS) Hypalon Paint (SRB) Eneclite Foam (RCC Prot. Cover)	Tile (ORB TPS)		
41	Metallics - BSM Residue (SRB) RTV, Tile (ORB TPS) Insulation Glass (ORB TPS) Calcite, Salt (Landing Site) Organics	Tile (ORB TPS) Salt (Landing Site)	Tile (ORB TPS)	Calcite (Landing Site) Fluorocarbon (Viton-ORB Umb) Foam (ORB C/O)	Fwd FRSI - Silicon Matl (ORB TPS)
31R	Metallics - BSM Residue (SRB) RTV, Tile (ORB TPS) Insulation Glass (ORB TPS) Calcite, Salt (Landing Site) Organics	Metallics - BSM Residue (SRB) RTV, Tile (ORB TPS) Insulation Glass (ORB TPS) Mica (Landing Site) Organics Foam Insulation (ET/SRB) Paint	RTV, Tile (ORB TPS) Insulation Glass (ORB TPS) Mica (Landing Site) Paint		
36	Metallics - BSM Residue (SRB) RTV, Tile (ORB TPS) Insulation Glass (ORB TPS) Mica, Salt (Landing Site) Paint	Rust - BSM Residue (SRB) Tile (ORB TPS) Paint Organics	RTV, Tile (ORB TPS) Insulation Glass (ORB TPS) Mica (Landing Site) Organics Microballoon (ET/SRB)	Rust - BSM Residue (SRB) RTV, Insulation Glass (ORB TPS) Microballoon (ET/SRB) Calcite (Landing Site) Foam, Organics (ORB Umb C/O)	

FIGURE 15. Orbiter Post Landing Microchemical Sample Results

STS	Sample Location					Other
	Windows	Wing RCC	Lower Tile Surface	Umbilical		
32R	Metallics - BSM Residue (SRB) RTV, Tile (ORB TPS) Insulation Glass (ORB TPS) Mica, Salt (Landing Site) Paint		Metallics - BSM Residue (SRB) Tile (ORB TPS) Carbon Fibers Titanium	Metallics - BSM Residue (SRB) RTV, Insulation Glass (ORB TPS) Phenolic Microballoon (ET/SRB) Quartz, Calcite (Landing Site) Organics	Crew Hatch Window - Rust - BSM Residue (SRB) - Alpha Quartz (TPS/Landing Site) - Paint - Organics	
33R	Metallics - BSM Residue (SRB) RTV, Tile (ORB TPS) Insulation Glass (ORB TPS) Micaeous Mat'l, Salt (Landing Site) Window Polish Residue (ORB) Paint	Metallics - BSM Residue (SRB) Tile (ORB TPS) Insulation Glass (ORB TPS) Mica, Spar, Salt (Landing Site) Organics	RTV, Tile (ORB TPS)	Rust - BSM Residue (SRB) RTV, Insulation Glass (ORB TPS) Phenolic Microballoon (ET/SRB) Paint Organics		
34	Metallics - BSM Residue (SRB) RTV, Tile (ORB TPS) Insulation Glass (ORB TPS) Alpha-Quartz, Silicates, Salt (US) Window Polish Residue (ORB)	Metallics - BSM Residue (SRB) RTV, Tile (ORB TPS) Insulation Glass (ORB TPS) Paint	RTV, Tile (ORB TPS) Stainless Steel Washer	RTV (ORB) Foam (ORB) Viton Rubber (ORB) Metallics - BSM Residue (SRB) Phenolic Microballoon (ET/SRB) Silicates, Calcium (Landing Site) Paint		
28R	Silicone (ORB FRCS Cover Adhesive)	Silicates (Landing Site) Paint Charred Silicone Brass Chip	RTV, Tile (ORB TPS) Clay, Sand, Quartz (Landing Site) Metallics - BSM Residue (SRB)	Sand, Silicates (Landing Site) Foam (ORB) RTV (ORB TPS) Koropon, Kepton (ORB) Metallics - BSM Residue (SRB)	OMS Pod - PVC Laminate (ORB TPS 'Shim')	
30R	Metallics - BSM Residue (SRB) RTV, Tile (ORB TPS) Insulation Glass (ORB TPS) Clay, Salt (Landing Site) Paint		Metallics - BSM Residue (SRB) RTV, Tile (ORB TPS) Gap Filler (ORB TPS) Clay, Feldspar (Landing Site)		Upper Tile - Tile, Gap Filler (ORB TPS)	
29R	RTV, Tile (ORB TPS) Metallics - BSM Residue (SRB) Ablator, Hypalon Paint (SRB)		Tile (ORB TPS) Insulation Glass (ORB TPS) Paint Muscovite - Metallics (Landing Site)	Tile (ORB TPS) Umbilical Foam (ORB) Paint Ablator, Hypalon Paint (SRB) Metallics - BSM Residue (SRB)	Upper Tile - Tile (ORB TPS)	
27R	RTV, Tile (ORB TPS)	Hypalon Paint (SRB)	RTV, Tile (ORB TPS) Ablator, Hypalon Paint (SRB)		OMS Pod - Iron Fiber - PDL Foam, FRL Paint (ET) - Ablator, Hypalon Paint (SRB)	
28R			RTV, Tile (ORB TPS) Paint Rust			

Sample locations vary per mission and not all locations are sampled for every mission.
() - identifies the most probable source for the material.
Metallics - includes mostly Aluminum and Carbon Steel alloys

FIGURE 15. Orbiter Post Landing Microchemical Sample Results

9.0 POST LAUNCH ANOMALIES

Based on the debris walkdowns and film/video review, seven post launch anomalies, but no In-Flight Anomalies (IFA), were observed on the STS-60 mission.

9.1 LAUNCH PAD/SHUTTLE LANDING FACILITY

1. South HDP shoe EPON shim material was intact, but debonded on HDP #1 and #2.

2. A greater than usual amount of ejecta (throat plug material, instafoam particles, deck/paint scale) from the RH SRB exhaust hole crossed the camera field of view after T-0.

9.2 EXTERNAL TANK

1. No items.

9.3 SOLID ROCKET BOOSTERS

1. The HDP #3 DCS plunger was obstructed by a frangible nut half. Although launch films showed no debris falling from the DCS/stud hole at lift off, post flight disassembly of the Debris Containment System revealed a retention of only 53 percent. The ordnance fragments may have been lost at water impact. The HDP #4 DCS plunger was obstructed by a frangible nut web and small ordnance fragments.

2. Aft skirt acreage TPS was generally in good condition, though MSA-2 was missing from four places on the 1860 ring frame and near the HDP #7 foot. The largest area of missing TPS measured 4" x 2". No significant amount of BTA was used on the aft skirt closeouts.

3. A greater than usual amount of instafoam, typically applied at the launch pad, was missing from the aft skirt aft ring. Exposed sections of K5NA were sooted and showed signs of heating.

9.4 ORBITER

1. A greater than usual number of tile damage sites occurred on the leading edges of the OMS pods and vertical stabilizer. Eleven of these hits had a major dimension greater than 1-inch. Depths ranged from 1/8 to 3/4 inches. This type of damage is usually attributed to impacts from higher density material, such as ice from the waste water dump.

2. The shim in the EO-2 "salad bowl" was partially debonded and displaced across the stud hole approximately 1/4-inch.



Appendix A. JSC Photographic Analysis Summary



Space Shuttle

Photographic and Television Analysis Project

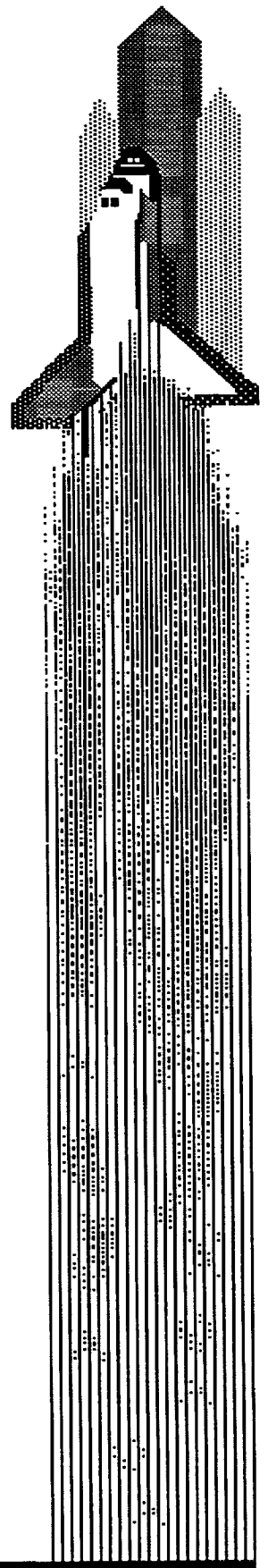
STS-60 Summary of Significant Events

March 9, 1994



National Aeronautics and
Space Administration

Lyndon B. Johnson Space Center
Houston, Texas 77058



Space Shuttle Photographic and Television Analysis Project


STS-60 Summary of Significant Events

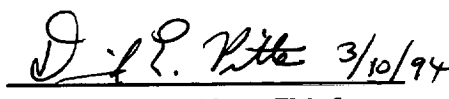
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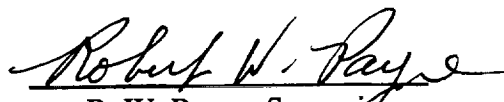
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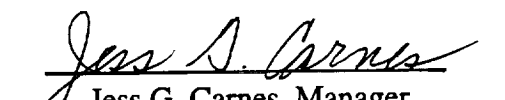
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1.0 Mission Summary

1.1 LAUNCH

Discovery (OV-103) launched on mission STS-60 from Pad A at 12:10:00.010 Coordinated Universal Time (UTC) on (February 3, 1994) (day 34) as seen on camera E-9. Solid Rocket Booster (SRB) separation occurred at 12:12:05.111 UTC as seen on camera E-207.

On launch day, 24 videos were screened. Following launch day, 54 films were reviewed. Film from camera E-222 was not delivered. No potential anomalies were observed during launch.

Detailed test objective (DTO)-0312 (photography of the external tank after separation) was performed using a handheld Nikon camera with a 300 mm lens and 2x extender. Thirty-seven frames of the external tank (ET) were acquired by the astronauts using the Nikon camera. Discovery is not equipped with umbilical well cameras.

1.2 ON ORBIT

ODERACS deploy was supported by calculating the velocity of the spheres as they left the Get-Away Special (GAS) can. No on orbit anomalies were identified.

1.3 LANDING

Discovery landed on runway 15 at Kennedy Space Center (KSC) (February 11, 1994). Eleven videos of the Orbiter's approach and landing were received. NASA Select, which uses multiple views real-time, was also received. Right main gear touchdown was at 42:19:19.21.860 UTC and left main gear touchdown occurred at 42:19:19.22.060 UTC as seen on Camera TV-33. Nose wheel touchdown occurred at 42:19:19.41.079 UTC as seen from camera TV-33. Wheel stop was at 42:19:20.11.210 UTC.

Fifteen landing films were received from KSC and screened. Camera EL-8 was not received. No major anomalies were noted in any of the approach, landing and rollout video views screened.

The following items were noted during the post-landing walk around: discoloration of thermal blankets near the front of both OMS pods; TPS erosion on the forward portion of the starboard OMS pod; a slight fraying of the DMHS at the base of SSME #3; loose material that appeared to be a sealant was visible around a couple of orifices inside the LO2 umbilical; TPS erosion on the base heat shield near the starboard OMS nozzle; tile damage on the nose gear starboard door; TPS damage along the left edge of the right outboard elevon and the underside of the left inboard elevon; visually noticeable tread wear was noted on both nose gear tires and the inboard tires for both main gears; discoloration of tiles and thermal blankets near both forward RCS thrusters.

1.4 TIMING ACTIVITIES

All launch videos had timing and film cameras E-1, E-2, E-3, E-4, E-5, E-6, E-7, E-8, E-9, E-10, E-11, E-12, E-13, E-14, E-15, E-16, E-17, E-18, E-19, E-20, E-25, E-26, E-52, E-54, E-57, E-59, E-211, E-224, EL-1, EL-2, EL-3, EL-4, EL-6, EL-7, EL-10, EL-12, EL-15, EL-19 and EL-20 had in-frame alphanumeric timing. These videos and films were used to time specific mission events during the initial screening. All of the landing videos had timing except cameras KTV-13L, SLF-North and SLF-South.

A timing discrepancy was discovered in the review of landing film cameras EL-7 and EL-15. Film camera EL-7 was found to have a -0.12 second timing offset. Film camera EL-15 was found to have a -75.89 second timing offset.

2.0 Summary of Significant Events

2.1 DEBRIS

2.1.1 Debris near the Time of Space Shuttle Main Engine (SSME) Ignition

2.1.1.1 LH2 and LO2 Tail Service Mast (TSM) T-0 Umbilical Disconnect Debris (Cameras E-17, E-18, E-19, E-20, E-76, E-77, OTV-049, OTV-050, OTV-051)

Normal ice debris was noted falling from the LH2 and LO2 TSM T-0 umbilical disconnect areas at SSME ignition through liftoff. A thin shiny piece of debris (possibly a tag) was noted from camera E-18 traveling from the LH2 TSM carrier assembly toward the Orbiter. None of the debris was observed to strike the vehicle. No follow-up action was requested.

2.1.1.2 Orange Debris Near LH2 ET/Orbiter Umbilical (Camera E-6, E-17, OTV-009)

A single piece of flexible orange-colored debris (possibly baggie material) fell from the lower right corner of the LH2 umbilical well area at T-2.550 seconds. This debris is similar in shape and color to the debris seen from camera E-17 at T-1.210 seconds and from camera E-6 at T-2.095 seconds near the aft end of the body flap and the right inboard elevon. No follow-up action was requested.

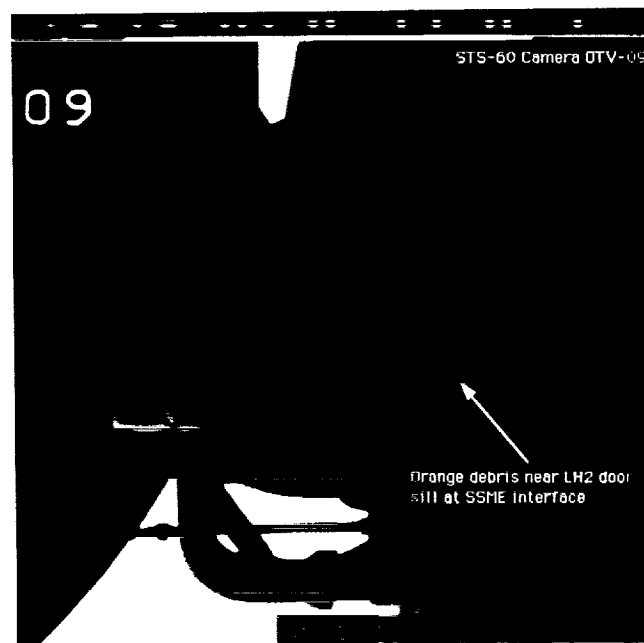


Figure 2.1.1.2 Orange debris near the LH2 umbilical door sill area noted at SSME startup. This debris is possibly umbilical baggie material.

2.1.1.3 LH2 and LO2 ET/Orbiter Umbilical Debris (Cameras E-4, E-5, E-6, E-15, E-16, E-17, E-18, E-25, E-31, OTV-009, OTV-054, OTV-063)

Normal ice debris was noted falling from the LH2 and LO2 ET/Orbiter umbilical disconnect areas at SSME ignition through liftoff. Debris was noted to strike the LH2 umbilical door sill. No apparent damage was observed. No follow-up action was requested.



2.0 Summary of Significant Events

2.1.1.4 Flexible Debris Traveling South near Cable Tray (Cameras E-6, OTV-054)

A small flexible piece of debris was noted traveling south near ET/Orbiter aft attach strut at T-0.605 seconds MET. The origin could not be determined nor could the debris be observed after it passed by the electrical cable tray.

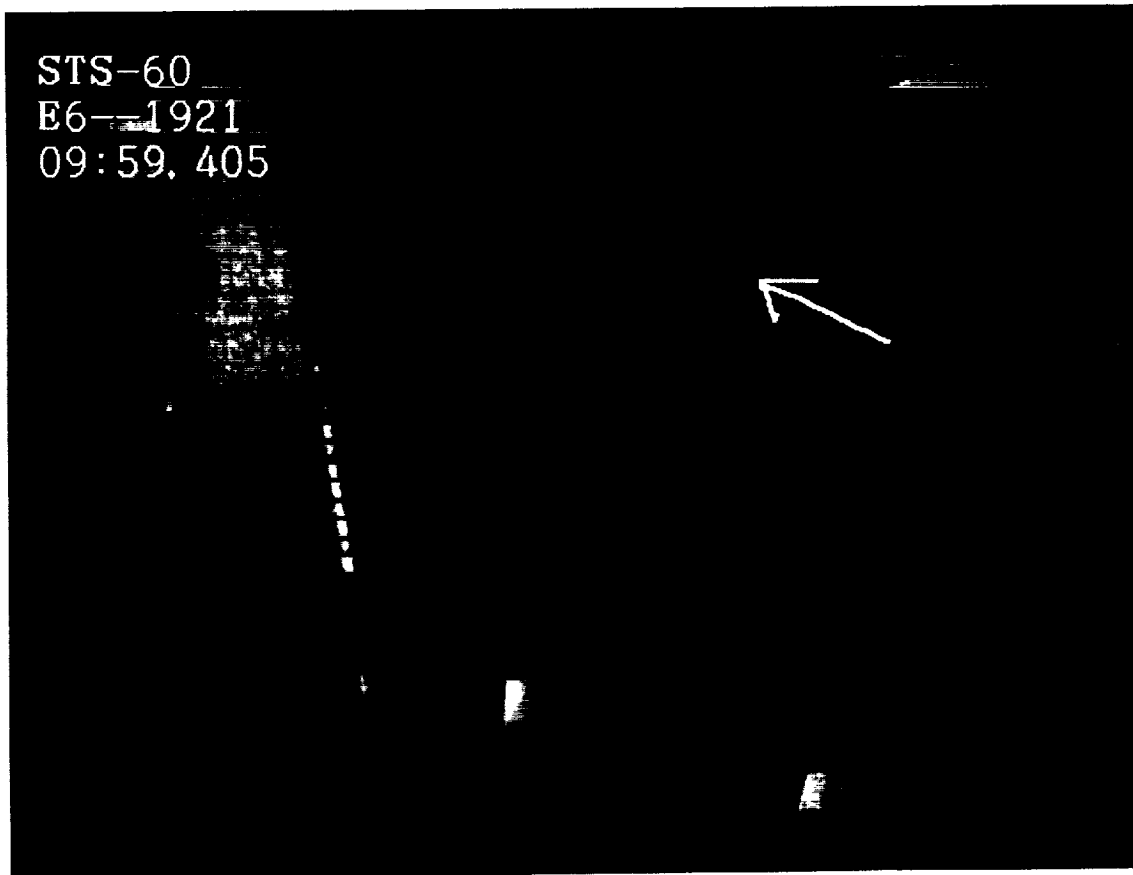


Figure 2.1.1.4 A single orange piece of debris near the right ET/Orbiter aft attach noted prior to liftoff. This debris traveled from right to left through the field of view.



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2.0 Summary of Significant Events

2.1.2 Debris near the Time of SRB Ignition

2.1.2.1 Debris Near Vertical Stabilizer (Camera OTV-071)

A single, small, dark piece of debris was first seen near the speed brake attach at the port side of the vertical stabilizer, rose slightly and then fell aft. The debris did not appear to strike the vehicle.



Figure 2.1.2.1 Dark debris near the vertical stabilizer noted at liftoff. The debris traveled in a vertical line above the rudder/speed brake then fell aft. This event was not observed during the screening of the launch films.

2.1.2.2 SRB Flame Duct Debris (Task #7) (Cameras E-5, E-8, E-9, E-10, E-11, E-15, E-16, E-57)

As on previous missions, several pieces of debris were noted originating from the SRB flame duct area after SRB ignition. None of the debris appeared to travel toward the Orbiter with significant velocity.

2.1.3 Debris After Liftoff

2.1.3.1 Debris Prior to and During Roll Maneuver (Cameras E-52, E-54, E-57, E-213, KTV-4A)

Multiple pieces of debris were seen falling aft of the Shuttle Launch Vehicle (SLV) at liftoff, throughout the roll maneuver on the launch tracking views. Most of the debris sightings were probably reaction control system (RCS) paper or ice from the ET/Orbiter umbilicals.



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2.0 Summary of Significant Events

2.1.3.2 Debris During Ascent (Cameras E-207, E-208, E-212, E-218, E-220, E-223)

During ascent, multiple pieces of debris exited the SRB exhaust plume between 65 and 80 seconds MET. None of the debris was observed to strike the vehicle. No follow-up action was requested.

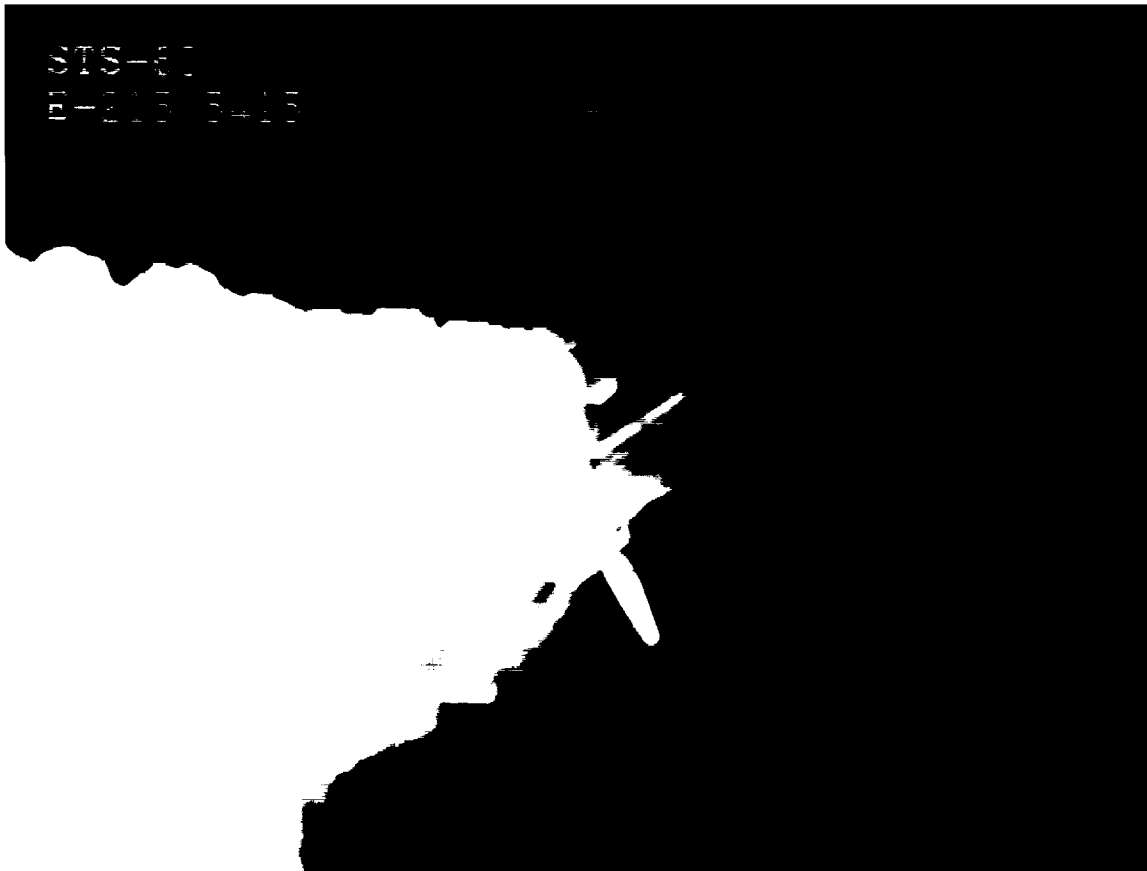


Figure 2.1.2.3 Debris during ascent noted along SRB plumes.

2.1.3.3 Debris Reported by the Crew (*Task #10*)

The following is a written transcript of the crew debris report provided by the STS-60 Commander to the Mission Control Center Capcom on February 3, 1994.

Capcom

Discovery, Houston, we are three minutes to LOS, if you have time now we can take a debris report, otherwise we could wait until after the burn.

Commander Charles Bolden

Okay, Charlie, we copy. It's going to be very brief. At Mach 8.3, Ken noticed some white specs going by W6, very small in size. Again at Mach 12.5, the same white specs. On the lefthand side of the vehicle, I was looking into the sun the whole time and noticed nothing.



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2.0 Summary of Significant Events

Capcom

Okay, Charlie, we copy. At Mach 8.3, some small white specs going by W6 and again at 12.5, the same small white specs and nothing on the left side.

Commander Charles Bolden

That's affirmative. And the windows right now don't look to be anything abnormal. Just the standard kind of haze that you get, but it's relatively clean.

Capcom

Okay. Great! We copy that.

2.2 MLP EVENTS

2.2.1 Flares in Hydrogen Ignitors (Cameras E-3, E-20, E-76)

Two flares were noted at the southwest hydrogen burn ignitor nozzle prior to SSME ignition. No follow up action was requested.

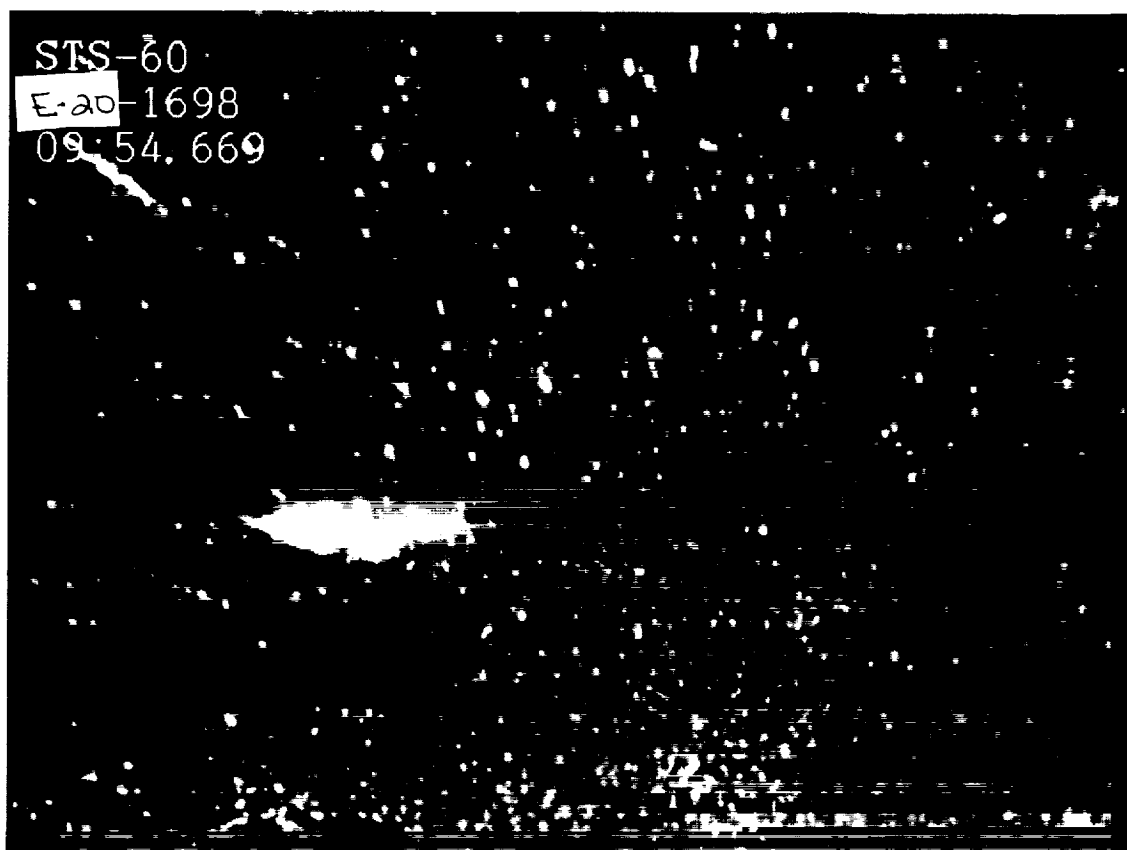


Figure 2.2.1 Flare in the southwest hydrogen ignitor during startup.



2.0 Summary of Significant Events

2.2.2 Orange Vapor (Possibly Free-Burning Hydrogen)

(Cameras E-2, E-3, E-5, E-15, E-17, E-18, E-20, E-62, E-63, E-76, E-77, OTV-163, OTV-070, OTV-071)

An orange vapor (possibly free-burning hydrogen) was seen curling under the body flap prior to SSME ignition. This event was noted on previous missions. No follow-up action was requested.

2.2.3 TPS Erosion

(Cameras E-17, E-18, E-19)

TPS erosion was noted on the base heat shield after SSME startup. Significant erosion was visible near the R2D RCS thruster. TPS erosion was observed on previous missions. No follow-up action was requested.



Figure 2.2.3 TPS erosion on the right side of the base heat shield during startup.

2.2.4 Flashes in SSME Plumes after SSME Ignition

(Cameras E-2, E-76)

Multiple flashes were noted in the SSME #1 plume prior to liftoff. These flashes in SSME exhaust plumes were seen on prior missions. No follow-up analysis was requested.



2.0 Summary of Significant Events

2.2.5 Rudder/Speed Brake Draining (Cameras E-52, E-54)

Fluid drained from the rudder/speed brake drain port after liftoff. Draining continued through tower clear. This event was observed on previous missions.

2.2.6 Loose Thermal Curtain Tape (Camera E-7)

A piece of loose RSRB thermal curtain tape was noted just after liftoff. This event was observed on previous missions. No follow-up action was requested.



Figure 2.2.6 A piece of loose thermal curtain tape noted on the north side of the RSRB.



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2.0 Summary of Significant Events

2.3 ASCENT EVENTS

2.3.1 Flares in SSME Plume

(Cameras ET-207, KTV-4A, E-205, E-207, E-211, E-213, E-223, E-224)

At least two flares were noted in the SSME plumes during ascent. This event was observed on previous missions. These flares were timed at 12:10:35.587 and 12:10:37.911 UTC or 35.576 and 37.901 seconds MET respectively.



Figure 2.3.2 Flare in SSME plume noted during ascent.

2.3.2 Body Flap Motion (Task #4)

(Cameras E-213, E-223)

Only slight body flap motion was visible during the time of maximum dynamic pressure (30-90 seconds MET). However, as part of an ongoing study of OV-103 missions, pad camera films E-17 and E-18 were reviewed for on-pad motion and frequency calculations. The time frame for the acquired data was during maximum motion which occurred between SSME ignition and throttle up (~T-3.775 seconds to T-2.775 seconds).

Of the frequency peaks identified during on-pad motion, global rotation was visible on both sides and torsion was identified on the port side of the flap. The maximum peak-to-peak deflection was 0.6 inches on the starboard side and 0.8 inches on the port side. These deflection measurements are similar to those seen on past missions.



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2.0 Summary of Significant Events

Film from cameras E-205, E-207, E-213 and E-223 were reviewed for body flap motion visible during ascent. Due to camera defocus and platform jitter during the time of maximum dynamic pressure, measurements were not taken.

2.3.3 Recirculation (Task #1) (Cameras E-205, E-207, ET-207)

The recirculation or expansion of burning gases at the aft end of the SLV prior to SRB separation has been seen on nearly all previous missions. The sighting of this event is dependent upon launch inclination angle and cloud cover during ascent. For STS-60, the start of recirculation was observed at about 91 seconds MET and the end was noted at approximately 109 seconds MET on camera E-205.

Cameras on which recirculation was observed for STS-60

CAMERA	START (seconds MET)	STOP (seconds MET)
ET-207	93	99
E-205*	91	109
E-207	92	101

* BEST VIEW OF RECIRCULATION

RECIRCULATION BY MISSION

MISSION	START (sec MET)	STOP (sec MET)	BEST VIEW	INCLIN. ANGLE
STS-26	92	112	E204	28.5°
STS-27	95	---	E205	57.0°
STS-29	92	112	E208	28.45°
STS-30	95	---	E204,E206	28.85°
STS-28	94	104	E205	57.0°
STS-34	95	---	E204	34.3°
STS-33	95	112	E206	28.45°
STS-32	100	109	E204,E206	28.5°
STS-36	93	103	E207	62.0°
STS-31	91	108	E206	28.45°
STS-41	91	112	E206	28.45°
STS-38	94	110	n/a	28.5°
STS-35	92	107	E212	28.45°
STS-37	92	107	E204	28.45°
STS-39	92	101	E205	57.0°
STS-40	---	---	---	39.0°
STS-43	94	110	E204	28.45°
STS-48	91	108	E205	57.0°
STS-44	95	113	E204	28.45°
STS-42	92	111	E205	57.0°
STS-45	97	109	E205	57.0°
STS-49	93	110	E212	28.35°
STS-50	98	110	E208	28.45°
STS-46	96	112	ET208	28.45°
STS-47	92	105	E205	57.0°
STS-52	92	113	E208	28.45°
STS-53	96	104	E207	57.0°
STS-54	94	108	E212	28.45°

2.0 Summary of Significant Events

STS-56	93	111	E205	57.0°
STS-55	94	110	E208	28.45°
STS-57	94	109	E204	28.5°
STS-51	94	112	E204	28.5°
STS-58	92	102	E204	39.0°
STS-61	93	113	E208	28.5°
STS-60	92	109	E205	57.0°

NOTE: No recirculation was observed on STS-40 films due to cloud cover and inclination angle. Intermittent LOV prevented acquisition of specific stop times for recirculation on STS-27, STS-30 and STS-34. Best view chosen by duration and clarity of event on films.

2.4 ON ORBIT EVENTS

2.4.1 Onboard Handheld Camera ET Analysis (Task #6) (STS--60-11-01 through 37)

STS-60 crew performed DTO-312 acquiring 37 views of the external tank (ET) from a single roll of 35 mm film. No confirmed damage to the external tank thermal protection system (TPS) acreage was observed. The entire ET was photographed except the +Y axis (right side) which was viewed at too oblique an angle for analysis. The photographs were taken by Sergei Krikalev using Nikon F4 camera with a 300 mm lens and a 2x extender (Method 3). The first photograph was taken 13 minutes and 54 seconds MET while the ET was at a distance of 858 meters from the Orbiter. The 36th photograph was taken at 24 minutes 39 seconds MET while the Orbiter was 3,469 meters from the Orbiter. The analysis results were reported to the Mission Evaluation Room (MER) Manager and to the standard distribution.

The external tank appeared to be in good condition on the handheld pictures. No confirmed damage was noted. Pieces of white debris were visible in the background on several of the frames. The white debris is probably frozen hydrogen from the LH2 umbilical.

The ET/Orbiter separation velocity was determined to be 4.0 meters per second which is similar to that seen on recent missions.

Astronaut Jan Davis provided approximately fifteen minutes of handheld camcorder video of the ET. Precise tracking of the ET enabled further screening of the ET for anomalies. There is no timing data on the video. No damage to the external tank was noted from the screening of the camcorder views.

2.0 Summary of Significant Events

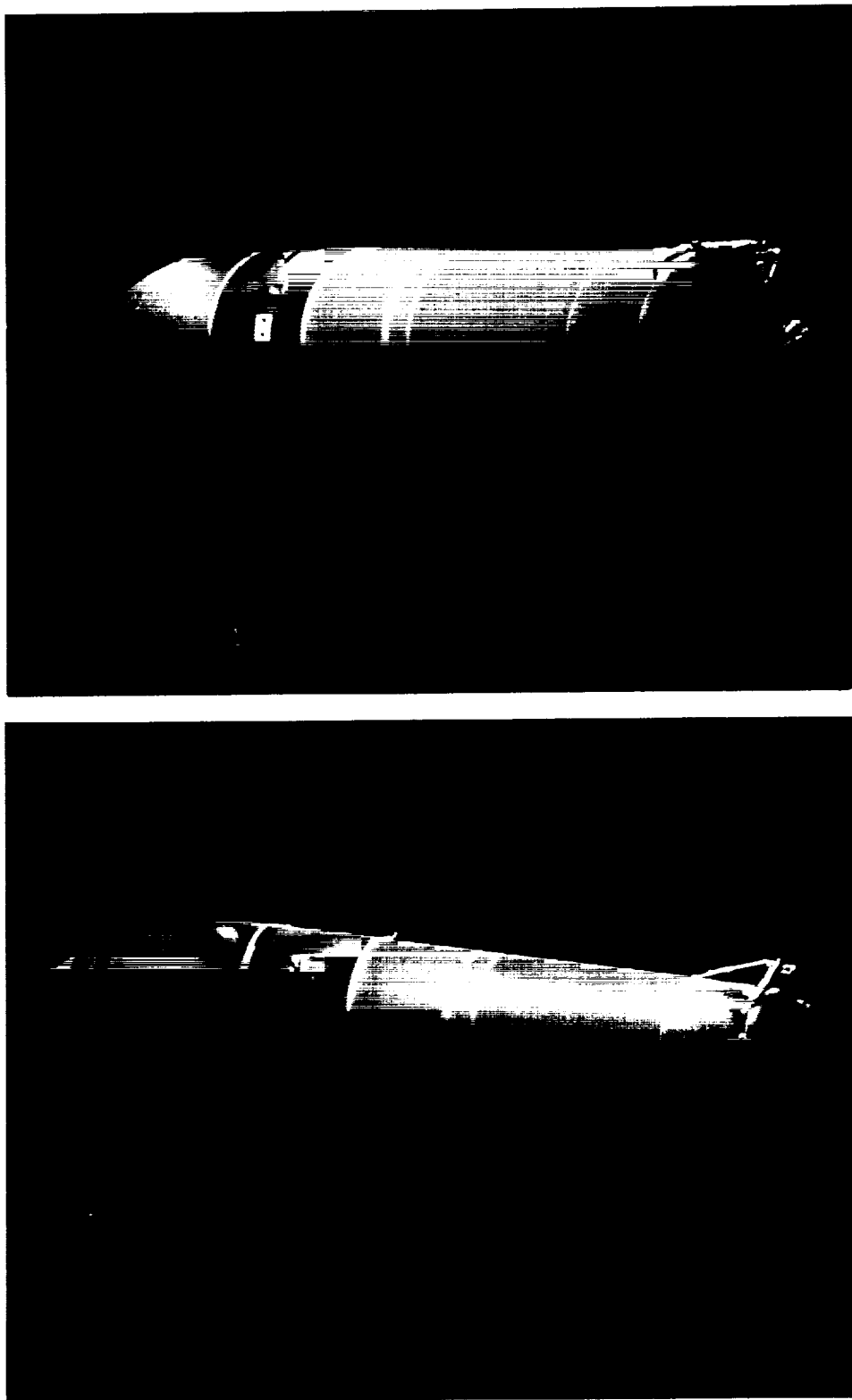


Figure 2.4.1 Onboard Handheld Camera Views of the ET
(*STS-60-11-06 top and STS-60-11-10 bottom*)



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2.0 Summary of Significant Events

2.4.2 ODERACS

The Photo/TV Project supported the ODERACS deployment on February 9. Analysts calculated exit velocities of 6 different calibration spheres launched from a Get-Away-Special Can located in the aft section of the cargo bay. These calculated velocities ranged from 1.53 to 3.34 meters per second and were used to help radar sites around the world track the spheres. (See the accompanying table for actual velocities). Follow-up analysis to determine separation angles between the spheres just after deployment is ongoing.

SEQ.	DESCR.	DIA. (inches)	EXP. VELOC. (meters/sec.)	CALC. VELOC (meters/sec.)	-EJECT.TIME (min:sec)UTC
1	polished stainless steel	4.0	3.39	3.34	54:23.674
2	sandblasted stainless steel	4.0	2.85	2.64	54:26.476
3	polished solid stainless steel	2.0	2.13	1.82	54:28.779
4	sandblasted solid stainless steel	2.0	1.85	1.86	54:31.448
5	chrome plated aluminum	6.0	1.61	1.55	54:35.886
6	sandblasted solid aluminum	6.0	1.40	1.53	54:38.422

2.0 Summary of Significant Events

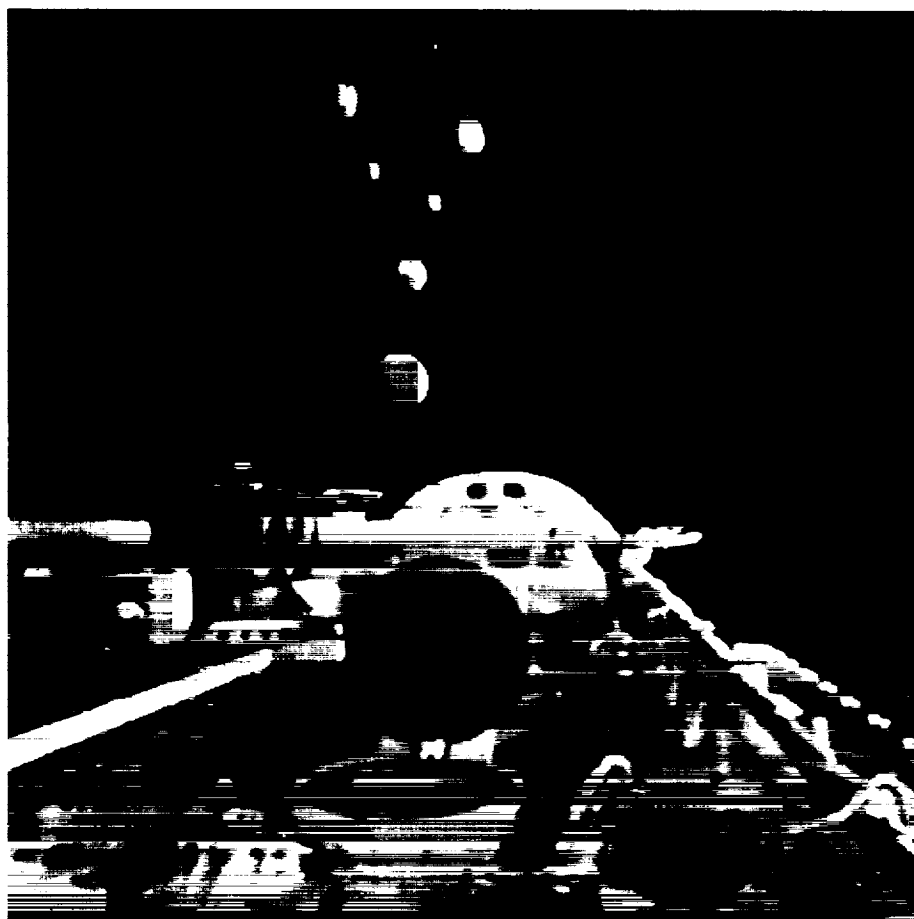


Figure 2.4.2 ODERACS Deploy

The above scene is a composite image showing the six calibration spheres as seen from camera C in the payload bay. This view illustrates the relative position and ejection sequence of the spheres but is actually composed from six different video frames.

2.5 LANDING EVENTS

2.5.1 Landing Sink Rate Analysis Using Video (*Task #3*) (*SLF-North, Camera TV-33*)

Camera SLF-North was used to determine the landing sink rate of the main gear. The analysis considered approximately one second of imagery immediately prior to touchdown. Data were gathered at a sample rate of 30 frames per second. Assumptions were made that the line of sight of the camera was perpendicular to the Orbiter y-axis and that any camera motion or vibration was negligible. Scaling information was determined by using the distance between the main gear struts. The vertical difference of the projected main gear point for two successive frames was multiplied by the scaling factor to find the change in height of the main gear over that interval. The main gear height above the runway was determined by assigning the frame of touchdown a height of 0 feet, and cumulatively adding the previous frames. These heights were then regressed with respect to time. The sink rate equals the slope of this regression line. The main gear sink rate was determined to be 1.8 feet per second.



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2.0 Summary of Significant Events

STS-60 Main Gear Sink Rate from Video

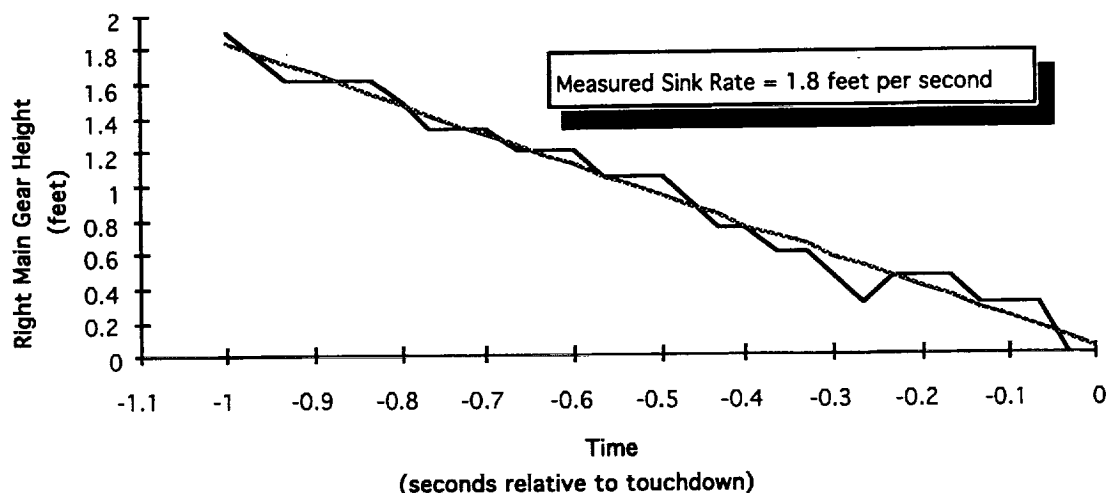


Figure 2.5.1a Graph of right main gear height versus time prior to touchdown - video

Camera TV-33 was used to determine the landing sink rate of the nose gear. The analysis considered approximately one second of imagery immediately prior to touchdown. Data were gathered at a sample rate of 30 frames per second. Scaling information was determined by using the relative locations of the vertical stabilizer, right and left main gear, and nose gear on each image. The y distance between the nose gear and the main gear was then, multiplied by the scale to find the height of the nose gear. These heights were then regressed with respect to time. The sink rate equals the slope of this regression line. The nose gear sink rate was determined to be 2.6 feet per second.

2.0 Summary of Significant Events

STS-60 Nose Gear Sink Rate from Video

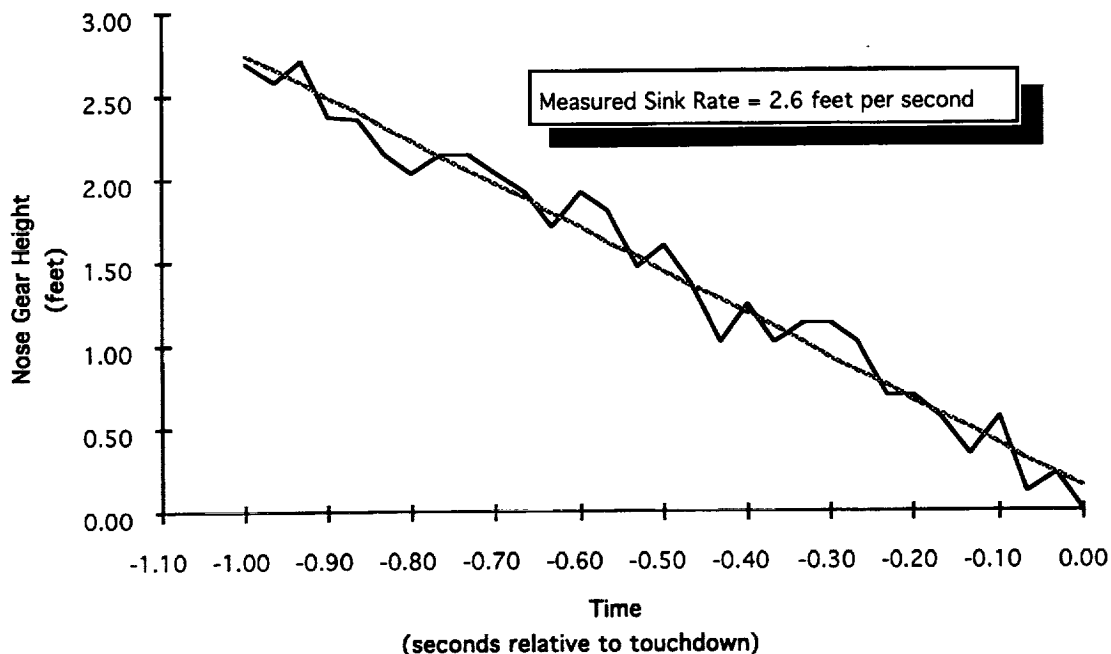


Figure 2.5.1b Graph of nose gear height versus time during rollout - video

2.5.2 Landing Sink Rate Analysis Using Film (*Task #3*) (Cameras EL-7, EL-12)

Camera EL-7 was used to determine the landing sink rate of the main gear. The analysis considered approximately one second of imagery immediately prior to touchdown. Data were gathered at a sample rate of 100 frames per second. Assumptions were made that the line of sight of the camera was perpendicular to the Orbiter y-axis and that any camera motion or vibration was negligible. Scaling information was determined by using the distance between the main gear struts. The vertical difference of the projected main gear point for two successive frames was multiplied by the scaling factor to find the change in height of the main gear over that interval. The main gear height above the runway was determined by assigning the frame of touchdown a height of 0 feet, and cumulatively adding the previous frames. These heights were then regressed with respect to time. Sink rate equals the slope of this regression line. The main gear sink rate was determined to be 2.3 feet per second.

2.0

Summary of Significant Events

STS-60 Main Gear Sink Rate from Film

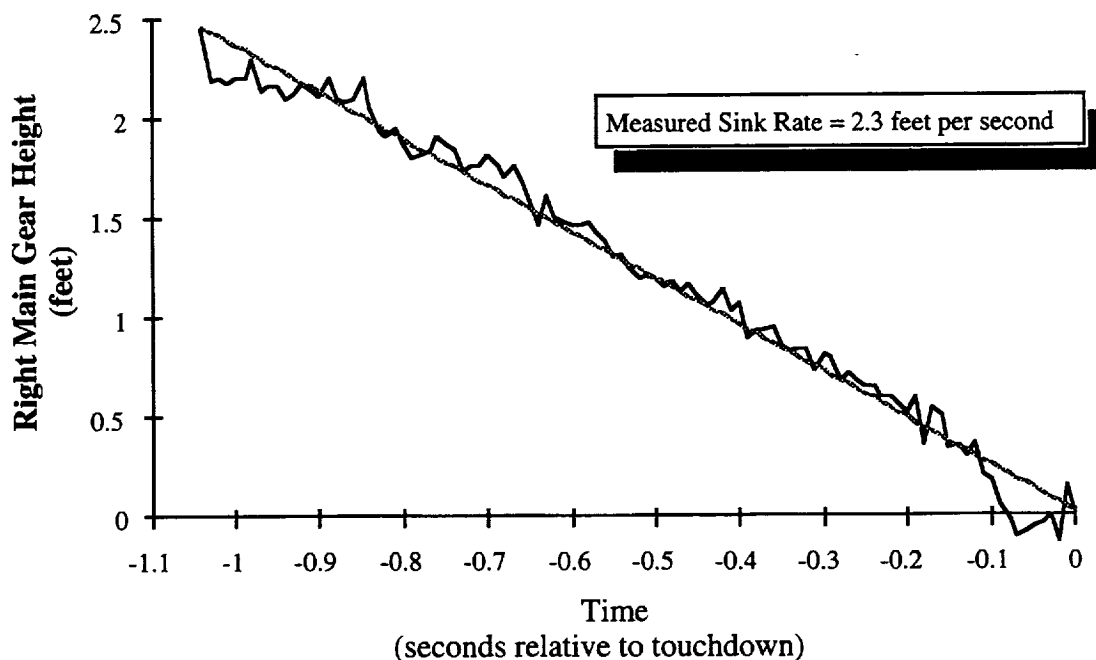


Figure 2.5.2a Graph of right main gear height versus time prior to touchdown - film

Camera EL-12 was used to determine the landing sink rate of the nose gear. The analysis considered approximately 0.7 seconds of imagery immediately prior to touchdown. Data were gathered at a sample rate of 50 frames per second. Scaling information was determined by using the relative locations of the vertical stabilizer, right and left main gear, and nose gear on each image. The effects of camera tracking was corrected by utilizing a runway reference point. The vertical difference of the projected nose gear point for two successive frames was multiplied by the scaling factor to find the change in height of the nose gear over that interval. The nose gear height above the runway was determined by assigning the frame of touchdown a height of 0 feet, and cumulatively adding the previous frames. These heights were then regressed with respect to time. Sink rate equals the slope of this regression line. The nose gear sink rate was determined to be 3.2 feet per second.

2.0

Summary of Significant Events

STS-60 Nose Gear Sink Rate from Film

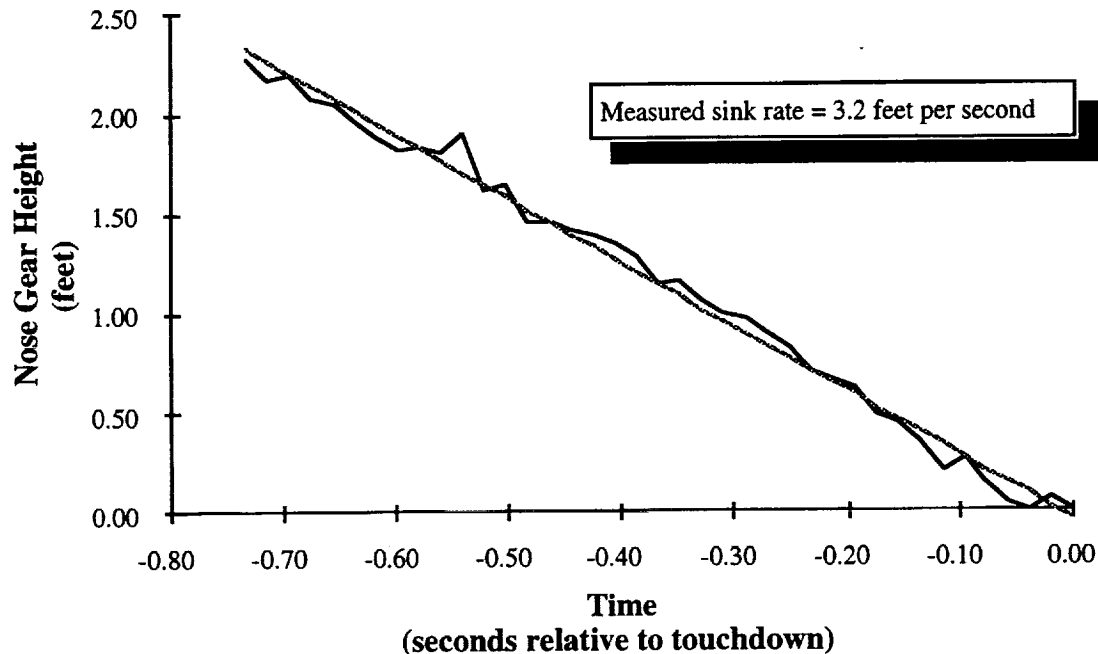


Figure 2.5.2b Graph of nose gear height versus time during rollout - film

2.5.3

Drag Chute Performance (Task #9)

(Cameras EL-1, EL-2, EL-3, EL-4, EL-5, EL-7, EL-9, EL-10, EL-12, EL-15, EL-19, EL-20, KTV-5L, KTV-6L, KTV-11L, KTV-15L, KTV-16L, KTV-33L, SLF-North, SLF-South)

The deployment of the drag chute appeared as expected. All drag chute event times were obtained from camera EL-10. Drag chute initiation was noted at 42:19:19:32.448 UTC. Pilot chute inflation was noted at 42:19:19:33.393 UTC. Bag release was noted at 42:19:19:33.122 UTC. Drag chute inflation in the reefed configuration was noted at 42:19:19:35.086 UTC. Drag chute inflation in the disreefed configuration was noted at 42:19:19:38.453 UTC. Chute release was noted at 042:19:19:54.885 UTC.

The landing of Discovery at the end of mission STS-60 marked the twelfth deployment of the Orbiter drag chute. All components of the drag chute appeared as expected. Standard analysis of the drag chute angles as a function of time was performed using the views from the film camera EL-7. This analysis is used to support the improvement of the aerodynamic math models currently in use. The maximum horizontal chute deflection within the analyzed interval was approximately 6.8 degrees. Figure 2.5.3 presents the measured heading angle versus time.

2.0 Summary of Significant Events

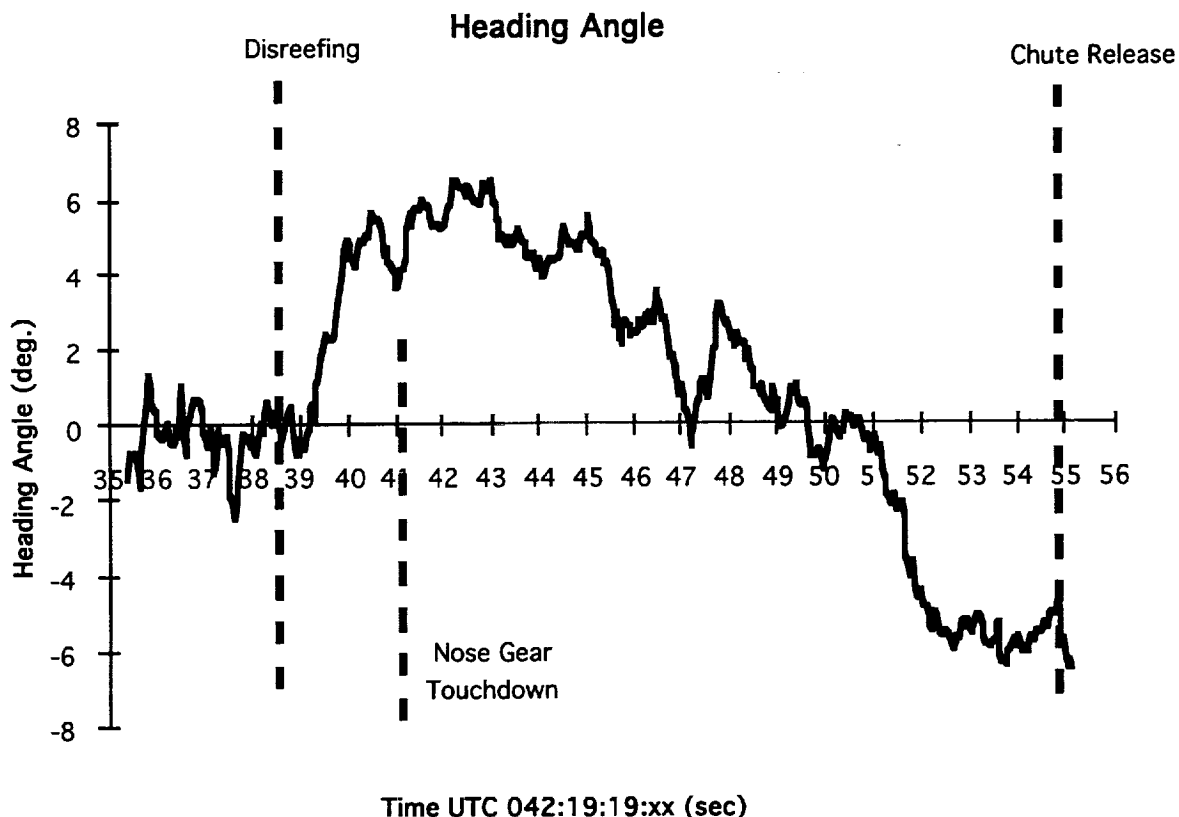


Figure 2.5.3 Graph of measured drag chute heading angle versus time during rollout

2.6 OTHER NORMAL EVENTS

Other normal events observed include: ice debris and vapor from the ET/Orbiter umbilical disconnects at SSME startup through liftoff; frost on the ET GOX vent louvers; slight motion of the both inboard and right outboard elevons at SSME startup through liftoff; ice and vapor from the ground umbilical carrier plate (GUCP) during SSME startup and GH2 vent arm retraction; debris in the exhaust cloud at the pad after liftoff; RCS paper debris prior to and after liftoff; ET aft dome outgassing and vapor from the SRB stiffener rings after liftoff; charring of the ET aft dome during ascent; debris in the SSME exhaust plume from liftoff through the roll maneuver; flares in the SSME exhaust plume after the roll maneuver; expansion waves; condensation around the SLV during ascent; linear optical distortions; dark puffs in SRB exhaust prior to SRB separation; SRB plume brightening; slag debris in the SRB exhaust plume during and after SRB separation. Normal events related to the pad are fixed service structure (FSS) deluge water spray activation; and mobile launch platform (MLP) water dump activation.

Appendix B. MSFC Photographic Analysis Summary



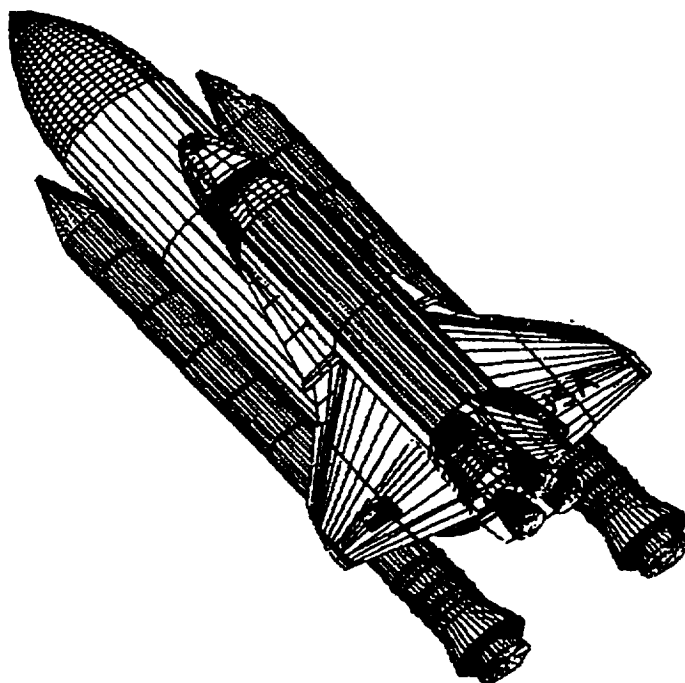
National Aeronautics and
Space Administration

George C. Marshall Space Flight Center
Marshall Space Flight Center, Alabama 35812

SPACE SHUTTLE

ENGINEERING PHOTOGRAPHIC ANALYSIS REPORT

STS-60





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ENGINEERING PHOTOGRAPHIC ANALYSIS REPORT

STS-60

FINAL

PREPARED BY:

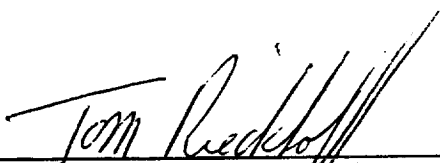
M. COVAN, B. EPPS, J. HIXSON
PHOTOGRAPHIC ANALYSIS/ROCKWELL/HSV

SUBMITTED BY:


JIM ULM

SUPERVISOR, LAUNCH OPERATIONS/ROCKWELL/HSV

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STS-60 ENGINEERING PHOTOGRAPHIC ANALYSIS REPORT

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* Photographs in the individual camera assessments are representative photographs and are not necessarily photographs taken from this particular launch.

February 23, 1994

I. INTRODUCTION

The launch of space shuttle mission STS-60, the eighteenth flight of the Orbiter Discovery occurred on February 3, 1994, at approximately 6:10 A.M. Central Standard Time from Launch Complex 39A (LC-39A), Kennedy Space Center (KSC), Florida. Extensive photographic and video coverage exists and has been evaluated to determine proper operation of the ground and flight hardware. Cameras (video and cine) providing this coverage are located on the fixed service structure (FSS), mobile launch platform (MLP), LC-39B perimeter sites, onboard the vehicle, and uprange and downrange tracking sites.

II. ENGINEERING ANALYSIS OBJECTIVES:

The planned engineering photographic and video analysis objectives for STS-60 included, but were not limited to the following:

- a. Overall facility and shuttle vehicle coverage for anomaly detection
- b. Verification of cameras, lighting and timing systems
- c. Determination of SRB PIC firing time and SRB separation time
- d. Verification of Thermal Protection System (TPS) integrity
- e. Correct operation of the following:
 1. Holddown post blast covers
 2. SSME ignition
 3. LH2 and LO2 17" disconnects
 4. GH2 umbilical
 5. TSM carrier plate umbilicals
 6. Free hydrogen ignitors
 7. Vehicle clearances
 8. GH2 vent line retraction and latch back
 9. Vehicle motion

There was one special test objective for this mission:

1. DTO-0312, ET photography after separation.

III. CAMERA COVERAGE ASSESSMENT:

Film was received from fifty-three of fifty-four requested cameras as well as video from all twenty-three requested cameras. The following table illustrates the camera data

received at MSFC for STS-60.

**Camera data received at MSFC
for STS-60**

	16mm	35mm	70mm	Video
MLP	22	0	0	3
FSS	7	0	0	3
Perimeter	3	3	0	6
Tracking	0	15	0	11
Onboard	2	1	0	0
Totals	34	19	0	23

Total number of films and videos received:	76
---	-----------

An individual motion picture camera assessment is provided as Appendix B. Appendix C contains detailed assessments of the video products received at MSFC.

a. Ground Camera Coverage:

The films were generally dark. The dark exposures were a result of the launch time, which occurred at the start of the launch window, during sunrise. The launch coverage was of lower quality than usual due to the dark exposure. No film was received from camera E-222 due to a mechanical failure of the camera.

b. Onboard Camera Assessment:

Each SRB forward skirt contained a camera to record the main parachute deployment. Both cameras operated properly and recorded data through water impact. Due to the lack of light, these cameras provided poor quality coverage. A 35mm hand-held camera was used to record film for evaluating the ET TPS integrity after ET separation. Thirty-seven excellent frames of the external tank were recorded.

IV. ANOMALIES/OBSERVATIONS:

a. General Observations:

While viewing the film, several events were noted which occur on most missions. These included: pad debris rising and

falling as the vehicle lifts off, debris north of MLP ejected from SRB blast holes, debris induced streaks in the SSME plume, ice falling from the 17 inch disconnects and umbilicals, and debris particles falling aft of the vehicle during ascent, which consist of RCS motor covers, hydrogen fire detection paper and purge barrier material. Body flap and inboard right elevon motions were noted during ascent. Venting from the speed brake was noted during ascent. A loose piece of thermal curtain tape was observed at liftoff on the right SRB as shown in figure 1.

A large amount of free burning hydrogen was visible during the SSME start transient as shown in figure 2. The behavior and location of this burning are typical of that seen previously. However, the larger visible amount may be due to the dark lighting conditions.

b. Glowing Debris from SRM Plume

Figure 3 is a film frame from camera E-220 showing glowing debris ejected from the SRM plume. Several pieces of glowing debris were noted during ascent. This debris is generally more visible during dark sky conditions due to the stronger contrast.

c. Main Parachute Crossing

One of the three main parachutes on the right SRB crossed between the other two and remained there until water impact. This event occurred after the main parachutes had fully deployed.

d. External Tank TPS Divots

Several TPS divots were along the - z axis of the tank. The divots were in a line and may be indicative of a debris impact. These divots are typical of previous observations.

V. ENGINEERING DATA RESULTS:

a. T-Zero Times:

T-Zero times are determined from cameras that view the SRB holddown posts numbers M-1, M-2, M-5 and M-6. These cameras record the explosive bolt combustion products.

POST	CAMERA POSITION	TIME (UTC)
M-1	E-9	34:12:10:00.008
M-2	E-8	34:12:10:00.008
M-5	E-12	34:12:10:00.009
M-6	E-13	too dark to determine

b. ET Tip Deflection:

Maximum ET tip deflection for this mission was determined

to be approximately 33 inches. Figure 4 is a data plot showing the measured motion of the ET tip in both the horizontal and vertical directions. A positive horizontal displacement represents motion in the -z direction. These data were derived from video camera OTV-161.

c. SRB Separation Time:

SRB separation time for STS-60 was determined to be 34:12:12:05.13 UTC as recorded by camera E-205.

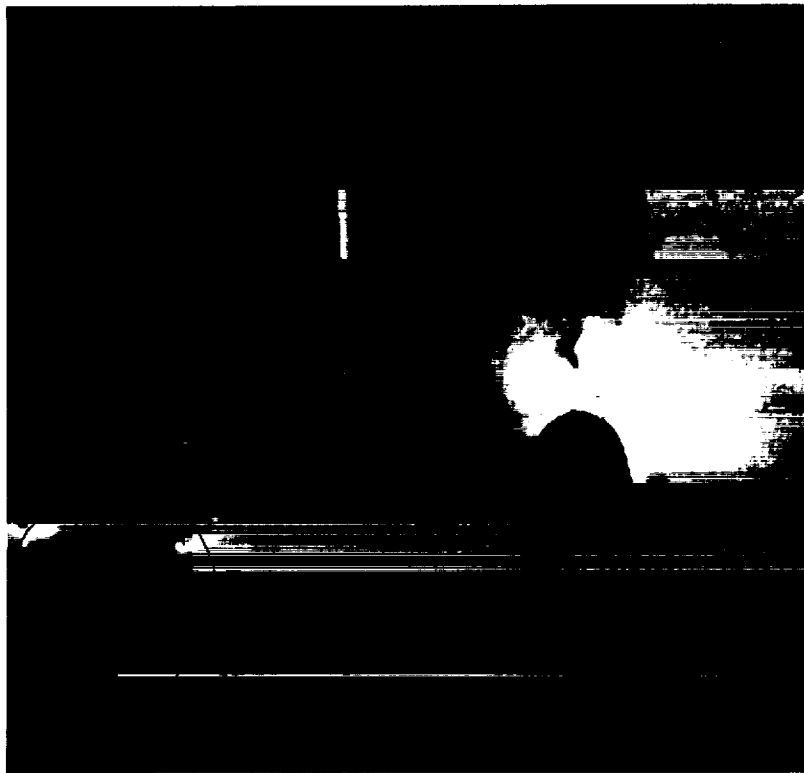


Figure 1.
Loose Piece of Thermal Curtain Tape

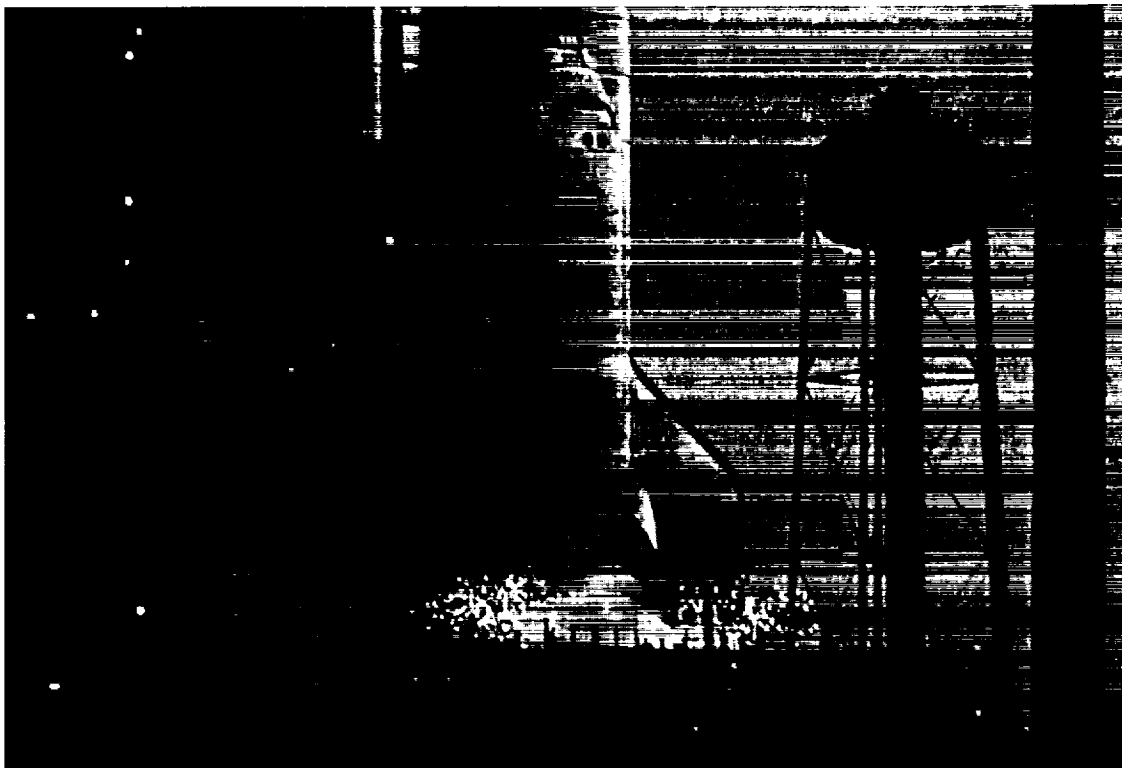


Figure 2.
Free Burning Hydrogen at SSME Ignition



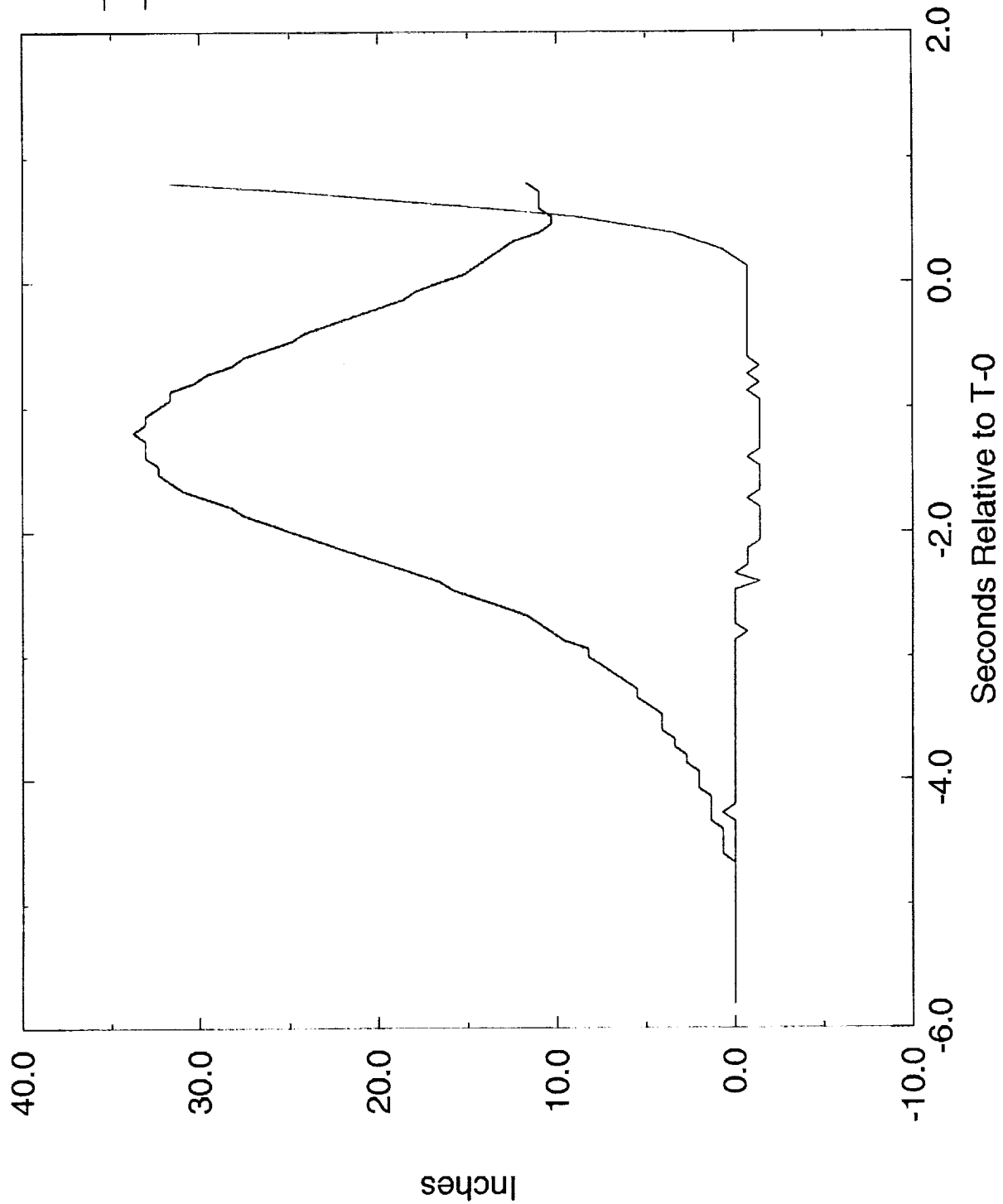


Figure 3.
Glowing Debris Particles Being Ejected from SRB Plume



ET Tip Deflection

STS-60 from camera OTV-061



Horizontal Motion
Vertical Motion

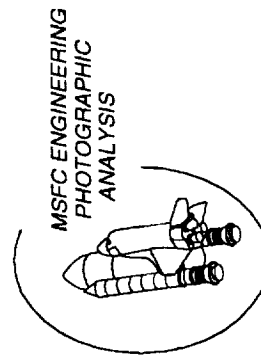


Figure 4



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Appendix C. Rockwell Photographic Analysis Summary



ATTACHMENT I

IL NO.: 279-300-5510
3/2/94

ROCKWELL ENGINEERING PHOTOGRAPHIC ANALYSIS SUMMARY REPORT FOR STS-60

Extensive photographic and video coverage was provided and has been evaluated to determine ground and flight performance. Cameras (cine and video) providing this coverage are located on the Launch Complex 39A Fixed Service Structure (FSS), Mobile Launch Platform (MLP), various perimeter sites, and uprange and downrange tracking sites for the STS-60 launch conducted on February 3, 1994, at 4:10 a.m. PST/GMT 034:12:10:00.000 from the Kennedy Space Center (KSC) and for the landing on February 11, 1994 at KSC at 11:19 a.m. PST/GMT 042:19:19:22. Rockwell received launch films from 81 cameras (57 cine, 24 video) and landing films from 27 cameras (15 cine, 12 video) to support the STS-60 photographic evaluation effort. Two films, E-222 and EL8 were not available due to camera malfunction.

Overall, the films showed STS-60 to be a clean flight. Several pieces of ice from the ET/Orbiter umbilical were shaken loose at SSME ignition, but no damage to the Orbiter Thermal Protection System (TPS) was apparent. The usual condensation and water vapors were seen at the ET aft dome and the SRB stiffener rings and dissipated after the completion of the roll maneuver. Charring of the ET aft dome, recirculation and brightening of the SRB plumes were normal. Booster Separation Motor (BSM) firing and SRB separation also appeared to be normal.

Nominal performance was seen for the MLP and FSS hardware. FSS deluge water was activated prior to SSME ignition and the MLP rainbirds were activated at approximately 1 second Mission Elapsed Time (MET), as is normal. All blast deflection shields closed prior to direct SRB exhaust plume impingement. Both TSM umbilicals released and retracted as designed. The ET GH₂ vent line carrier dropped normally and latched securely with a slight rebound. No anomalies were identified with the ET/ORB LH₂ umbilical hydrogen dispersal system hardware.

STS-60 was the twentieth flight with the optimized attach link in the SRB holddown support post Debris Containment Systems (DCS's). No holddown post hangups were observed.

No major or significant events were observed or identified. Events noted by the Rockwell film/video users during the review and analysis of the STS-60 photographic items are summarized in the following comments. These events are not considered to be a constraint to next flight.

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COMMENTS

1. Two flares were noted in the southwest hydrogen burn-off system nozzle just prior to SSME ignition on cameras E-3, E-20 and E-76. This may indicate the presence of excess hydrogen. No follow-up action is planned.
- 2.. On cameras OTV-163, OTV-170, OTV-071, E-2, E-3, E-5, E-15, E-17, E-18, E-20, E-52, E-76 and E-77, orange vapor (possibly free burning hydrogen) was seen drifting from beneath the SSME'S upward to the left OMS pod just prior to ignition. This vapor has been observed on previous flights and no follow-on work is scheduled.
3. On cameras E-19 and E-20, a white line was noted at the base of SSME #2 inside the Dome Mounted Heat Shield from ignition through liftoff. Films from previous missions (STS-61 and STS-56) were compared and the white line was visible on STS-56. A review of this event with the RI/DNY propulsion engineers concluded the white circular line was frost/ice buildup and was corroborated by the JSC and KSC film analysis teams. No further follow-up action is planned.
4. Flashes were observed in the SSME #1 plume at SSME ignition (cameras E-2 and E-76). Flashes in the SSME plumes have been seen on previous missions. No follow-up action is planned.
5. A piece of light colored debris was seen falling past the aft end of the body flap and the right inboard elevon during SSME ignition on cameras OTV-009, E-6 and E-17. This debris was probably mylar tape from the ET/Orbiter umbilical purge barrier. No follow-up action is planned.
6. On cameras E-18, a thin metallic - looking piece of debris (possibly a tag) was noted near the body flap hinge area outer edge. The debris did not appear to strike the vehicle. No follow-up action is planned.
7. On cameras OTV-009, OTV-054, OTV-063, E-4, E-5, E-6, E-15, E-16, E-17, E-18, E-25 and E-31, normal ice debris was seen falling from the LH2 and LO2 ET/Orbiter umbilical disconnect areas at SSME ignition through liftoff. Several of these particles contacted the LH2 umbilical sill, but no damage was detected. No follow-up action is planned.
8. A piece of loose thermal curtain tape was noted on the right SRB just after liftoff on camera E-7. No follow-up action is planned.
9. On camera E-54, fluid (water) was observed draining from the rudder speed brake drain port from liftoff through tower clear. This event has been noted on previous missions. No follow-up action is planned.
10. On cameras E-205, E-207, E-211, E-213, E-223 and E-224, four flares were

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observed in the SSME plumes during ascent. Flares have been noted on previous missions. No follow-up action is planned.

11. Numerous pieces of light colored debris were seen falling aft of the Shuttle Launch Vehicle and also exiting the SRB exhaust plume during ascent and prior to SRB separation (Cameras E-207, E208, E212, E213 and E220). This debris was probably RCS paper, ice from the ET/Orbiter umbilicals or SRB propellant particles. This event has been noted on previous missions. No follow-up action is planned.
12. The following events have been reported on previous missions and observed on STS-60. These are not of major concern, but are documented here for information only:
 - Ice debris falling from the ET/Orbiter Umbilical disconnect area
 - Debris (Insta-foam, water trough) in the holddown post area and MLP
 - Charring of the ET aft dome
 - ET aft dome outgassing after liftoff
 - RCS Paper debris
 - Recirculation or expansion of burning gasses at the aft end of the SLV prior to SRB separation
 - Slight TPS erosion on the base heat shield during SSME start-up
 - Twang motion
 - Body flap motion during the maximum dynamic pressure (MAX-Q) region which appeared to have an amplitude and frequency similar to those of previous missions
 - Linear optical distortion, possibly caused by shock waves or ambient meteorological conditions near the vehicle, during ascent
 - Slag in SRB plume after separation
 - Vapor from the SRB stiffener rings after liftoff
 - Fore-and aft movement of the Orbiter base heat shield in the centerline area between the SSME cluster at engine start-up

13. Camera E33 and E41 - OMRSD File IX Vol. 5, Requirement No. DV08P.010 requires an analysis of launch pad film data to verify that the initial ascent clearance separation between the left SRB outer mold line and the falling ET umbilical structure does not violate the acceptable margin of safety.

A qualitative assessment has been conducted and positive clearances between the left SRB and the ET vent umbilical have been verified. The films showed nominal launch pad hardware performance, and no anomalies were observed for the SRB body trajectory.

14. Cameras E7-16-OMRSD File IX Vol. 5, Requirement No. DV08P.020 requires an

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analysis of film data of SRM nozzle during liftoff to verify nozzle to holddown post drift clearance.

A qualitative assessment of the launch films has been completed. No anomalies were observed for the SRM nozzle trajectory and positive clearances between the SRB nozzles and the holddown posts were verified.

15. The landing of STS-60 occurred on Runway 15 at the KSC Shuttle Landing Facility. Good video and film coverage were obtained and no anomalous events were observed. The flight marked the thirteenth use of the orbiter drag chute. The drag parachute system performed as expected. All sequenced events occurred as expected and no hardware anomalies were observed.

Any questions concerning this report should be directed to the undersigned.

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